SCIENTIFIC INVESTIGATIONS WITH THE DATA BASE HEAO-1 SCANNING MODULATOR COLLIMATOR

NASA Grant NAG8-496

Final Report

For the Period 1 October 1984 through 30 September 1991

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1 Introduction

NASA Grant NAG8-496, Scientific Investigations with the Data Base of the HEAO-1 Scanning Modulation Collimator, is a follow-on to our work under Contract NAS8-30453, the Scanning Modulation Collimator experiment provided for the first High Energy Astronomy Observatory (HEAO-1). This final report encompasses the scope of the total project, as our final report to NAS8-30453 stated would be done. For brevity, most information is provided via reference to our previous reports and proposals already submitted to MSFC. A summary of our hardware and data processing is reproduced here as Appendix A.

The hardware specification for the Scanning Modulation Collimator (MC) experiment on HEAO-1 was to measure positions of bright ($> 10^{-11}$ ergs/cm^{2}s), hard (1 to 15 keV) x-ray sources to 5–10 arcsec, and to measure their size and structure in three energy bands down to 10 arcsec resolution. The scientific purpose of this specification was to enable the identification of these x-rays sources with optical and radio objects in order to elucidate the x-ray emission mechanism and the nature of the candidate astronomical system.

SAO has served as Principal Investigator for this experiment (under Dr. Herbert Gursky until June 1978, and Dr. Daniel Schwartz thereafter). In this role we were responsible for the concepts and requirements; supervision of the design, manufacture, and test by our hardware contractor American Science and Engineering (AS&E); and for mission operations, data reduction, scientific analysis, and publication of scientific results. In all these tasks we functioned as a single team with our Co-Principal Investigator Dr. Hale Bradt, and assisted by his entire staff at MIT.

The experiment was an outstanding success. Hardware systems functioned perfectly, although loss of one (out of eight) proportional counter degraded our sensitivity by about 10%. Our aspect solution of 7 arcsec precision, allowed us to achieve statistics-limited location precision for all but the strongest sources. We vigorously pursued a strategy of determining the scientific importance of each identification, and of publishing each scientific result as it came along.

2 Progress of the NAG8-496 Efforts

Efforts for the interval 1 October 1984 through 31 March 1987 are summarized in our progress reports Nov. 1 through 5, submitted under single cover in March 1987. Progress from 1 April 1987 through end of grant on 30 September 1990 is summarized chronologically as follows:

November 1987

Another 7-night observing run at Kitt Peak on the 36″ Schmidt yielded 27 new prism plates of A-3/NRL unidentified x-ray source areas. An observing run at McGraw-Hill obtained observations on two nights, giving identifications with 2 RS CVn stars, a cataclysmic variable, a candidate BL Lac object and an unclassified H-alpha emitter associated with an Einstein source under an IPC rib.

Work is underway on a poster session on clusters of galaxies, for the AAS meeting in January. Photo work has also been started for an AAT observing run in February. Archiving of A-3 finding chart maps continues.

A data disk crash has left some data temporarily inaccessible. A new disk will be built, and the heads cleaned and aligned on the affected drive. The DG dual-access tape drive still awaits repair.

December 1987, January and February 1988

The Trident T-200 data disk which experienced a head crash last month, was rebuilt and duplicated data files were loaded from back-up tapes. Versatec print-head problems occurred several times, but were overcome by resetting and adjusting the angle of the print-head.

Photographic fields were reproduced for 22 southern hemisphere A-1/A-3 x-ray sources, to be worked up as finding charts for a February AAT observing run.

A-3 results were analyzed and mapped for Abell clusters for a poster session at the AAS meeting in January. Work continues on the archiving of A-3 unidentified results.

April and May 1988

All Trident and Century disks were cleaned and inspected. One Trident data disk failed inspection and has subsequently been replaced and rebuilt.

A total of thirteen new finding charts were produced from recently analyzed A-3 data for observing runs. Thirty-four new Schmidt 2-degree prism plates were obtained during a nine-night run at CTIO, and were scanned during the 2 cloudy nights. Several interesting emission-line objects were found to be well associated with the A-1 LOP.

June 1988

A draft paper on the new BL Lac identification H1720+117, was prepared (by Brissenden) and reviewed internally. R. Remillard is nearing completion of the nine "mini-catalogs" which summarize the entire identification content of the HEAO-1 NRL source catalog.

September 1988

The nine mini-catalogs have been prepared, summarizing the status of all HEAO-1 identifications in categories as follows: AGN, BL Lac Objects, Cataclysmic Variables, Binaries, Be Stars, Clusters of Galaxies, RS CVn-like stars, Supernova Remnants, and Miscellaneous. NASA headquarters has deemed that the PI program will continue for two final years, FY89 and 90. In response to their direction for preserving the HEAO-1 data we have made a plan to publish the NRL catalog as a single table, in right ascension order, giving the identification status of every object. (The catalog will contain the 842 entries of the NRL survey, plus about 40 sources which appear later in the HEAO mission.) This will be followed by the 9 tables of mini-catalogs, each of which give supplementary information relevant to the particular class of object (e.g., redshifts for extragalactic objects).

October 1988

As a follow up to earlier VLA work, fifty-eight interesting radio sources relating to 12 LASS x-ray sources were measured and photographed to search for optical counterparts. Spectroscopy will be performed on all hopefuls. Fourteen new finding charts are being constructed for unidentified A-3/LASS sources visible in the southern sky during a December observing run.

A major head crash during September resulted in the loss of five T-200 Trident disks. Upon inspection one 40mb disk also had hard errors, and an additional one was found to have 'too many top platters' and removed from service. Nineteen heads had to be replaced, and heads were cleaned and aligned on all four drives. Two I/O boards were found to have blown and were replaced. The drives were brought up on the system, and four of the lost disks were rebuilt. Intermittent problems with the low density DG tape drive still persist causing vacuum loss when loading tapes.

December 1988

Seven unmasked IPC sources with A-3 results were worked up for further optical studies. Fourteen new A-3/NRL finding charts were made for a December observing run at CTIO. Nine figures were prepared for an RS CVn paper, and a contour map figure was prepared for an unmasked IPC source.

The CTIO observing run appears to have been highly successful with possibly ten to fifteen new identifications of southern x-ray sources.

Tape drive problems still persist. The power supply now appears to be unreliable. One 200mb data disk was rebuilt, and most of the data files were replaced.

February 1989

Ten newly discovered IPC unmasked source possibilities were mapped with A-3 error boxes, finding charts were made, and eight were found to be interesting enough to warrant further investigation as IPC/A-3/A-1 x-ray sources. During three recent observing runs 28 new identifications of x-ray sources have been made, including many QSO, several BL Lac, RS CVn's and CV's. Precise positions of many of the new objects are being measured. Of particular interest are a quasar with m=13.7, z=0.09 identified with H1033-142, and an optically shrouded luminous object in the LMC which we previously noted as peculiar and now identify with the x-ray source H0453-75.

Three scientific papers are in progress which will present a total of 39 new quasar and Seyfert ID's. Photographic work for these papers is also underway.

The two Century disk drives were adjusted and heads realigned after both malfunctioned simultaneously. Both are back on line now. We await the installation of a "new" (hand-me-down) dual-density DG tape drive to replace one with a burnt-out power supply.

August 1989

A Cerro Tololo nine-night observing run yielded 36 objective prism plates and 8 uv-blue direct plates of A-3 x-ray source fields. These plates were scanned, and interesting objects marked for further observations at the Anglo-Australian Telescope in September.

Rebinning of the original A-3 data at new interesting locations continues, and is about 5/8 complete. Mapping of the A-3 x-ray diamonds is now done on the MIT SUN system, and figures are thereby camera-ready from the laser printer.

Three papers of A-3 identifications are underway. These include 35 emission-line AGN's, 6 cataclysmic variables and 2 BL Lac's.

October 1989

Work progresses on the final LASS/A-3 survey Ingres database, with approximately 75% of the identified source information complete. Appropriate query and report forms are being built for each spectral class to facilitate access by the community.

Approximately thirty new x-ray sources have been identified during two recent observing runs. Three new publications of previous identifications are in progress.

April 1990

Work continues on the final HEAO-1/MC LASS catalog of identified x-ray sources, both the hardcopy version for publication, and the Ingres data-base version. At present the catalog contains 660 identifications.

A recent A-3 observing run yielded 20 new identifications whose exact positions will be measured. Approximately 300 sources with A-3 results remain unidentified. Of these, the brighter LASS detections are undergoing A-3 LASS analysis to confirm the LASS positions.

Fortran 5 .dx file analysis source programs have been ported to the SUN system, and are undergoing conversion to SUN Fortran 77. The .dx files and resulting answer.ct files are presently being written to WORM disks. A C program has been written to read the answer.ct's as well as many interesting and previous x-ray catalogs, and to output a SMONGO-readable file.

The DG computer was found to have blown a fuse due to a power glitch. The fuse has been replaced and no other problems were found. A high voltage power supply was replaced in the Versatec printer. Other DG system hardware continues to function satisfactorily.

August 1990

All .dx file analysis source programs have been successfully converted to f77 and ported to the SUN/UNIX system. The programs will undergo final testing during the next month to ensure compatibility. The INGRES data base of final A-3 results in on-line and will be updated one last time. All DG equipment is functional.

October 1990

The A-3 data reduction and analysis has been completed after 13 highly successful years. We have shutdown all Data General and associated equipment, which are now awaiting return shipment to NASA. A-3 raw tapes are expected to be stored until they can conveniently be transferred to DAT tapes; binned data tapes are currently being WORMed at Penn State;

All A-3 software has been archived on 9-track tapes; all other obsolete 9-track tapes are ready for shipment to Goddard's Tape Retrieval Center.

The A-1/NRL catalog of final results is available in hard-copy format, and as an INGRES database on the SUNS. Two more A-3 papers which document identification of 37 new AGN's are about to be submitted of publication. A-3 data analysis of sources from the three binning catalogs is now fully supported by the SUN/UNIX system. Software necessary for the rebinning of raw data has been converted to AOS format, assuring that the tapes will be readable via "AOSLOAD" directly to the SUNS.

Subsequently, all equipment and magnetic tapes have been officially returned to NASA.

3 Summary of Scientific Results

Table 3.1 summarizes the A-3 locations of hard x-ray sources identified with optical objects. The table omits about 200 A-3 locations of x-ray sources which do not yet have firm identifications. Objects are in nine catagories as follows: AC=Active Coronal star, usually an RS CVn type object; AGN=active galactic nuclei, emission line objects; BL=BL Lac type object; CG=cluster of galaxies; CV=cataclysmic variable; Misc.=miscellaneous, including nearby galaxies, and galactic objects; SNR=supernova remnant; XRB=classical x-ray binaries, neutron star or black hole accreting from an OB supergiant or low mass companion; and XRB-Be=x-ray binary accreting from a Be star companion.

TABLE 3.1

HEAO-1 SCANNING MODULATION COLLIMATOR
IDENTIFICATIONS OF HARD X-RAY SOURCES

NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H0003+200	Mkn_335	AGN	1H0136-681	BL_Hyi	CV
1H0007+731	CTA1	SNR	1H0137-403	AGN-Steiner	AGN
1H2358+484	IW_Cas	AC	1H0140+393	B2_0139+39B	AGN
1H0014+111	IIIZw2	AGN	1H0132+607	X0142+614	XRB
1H0008-745	SAO255646	AC	1H0135-346	ESO353-G38	AGN
1H2357-126	WW_Cet	CV	1H0143-239	SAO167287	AC
1H0016-257	EXO_QSO	AGN	1H0150-537	H0147-537	AGN
1H0018+280	A21	CG	1H0151+359	A262	CG
1H0017+073	A28	CG	1H0157+142	TT_Ari	CV
1H0022+638	Tycho_SNR	SNR	1H0201-029	H0204-023	CV
1H0024-296	IR0027-2859	AGN	1H0203+513	1E0206+521	AGN
1H0042-093	A85	CG	1H0215-007	Mrk_590	AGN
1H0039+408	M31	Misc.	1H0217-639	H0213-647	AGN
1H0043+294	Sy0048+29	AGN	1H0219+625	HB3	SNR
1H0054-729	SMCX-3	XRB-Be	1H0212-172	PKS0219-164	BL
1H0048+250	PG0052+251	AGN	1H0219-710	HD14643	AC
1H0052-015	A119	CG	1H0226-296	S0258	CG
1H0053+604	g_Cas	XRB-Be	1H0218+304	Mrk_1040	AGN
1H0057-670	S0112	CG	1H0230-356.B	Q0226-360	AGN
1H0101-439	star	AC	1H0226-448*	SAO215947	AC
1H0106+324	Mkn_352	AGN	1H0227-094	NGC985	AGN
1H0101-241	A140	CG	1H0230-356.A	SAO193793	AC
1H0101-221	A133	CG	1H0235-525	AGN-Ward	AGN
1H0102-469	S0107-462	CG	1H0239-585*	Q0239-591	AGN
1H0102+017	A147	CG	3H0237-23	PKS0237-23	AGN
1H0103-762	H0107-750	XRB-Be	1H0239-215	PKS0240-217	CG
1H0113-148	Mkn_1152	AGN	1H0240+621	2S0241+622	AGN
1H0115+635	2S0115+63	XRB-Be	1H0241+364	A376	CG
3H0114+650	LSI+65_010	XRB-Be	1H0244+001	NGC1068	AGN
X0115-737	SMCX-1	XRB	1H0247-370	SAO193879	AC
1H0112+141	A175	CG	1H0251+414	AWM7(N1129)	CG
1H0122-281.A	Ton_S210	AGN	1H0256-617	SAO248669	AC
1H0122-281.B	H0117-286	AGN	1H0253+058	A400	CG
1H0121-353	NGC526A	AGN	1H0253+138	A401	CG
1H0122-590	Fair_9	AGN	1H0301-106	AGN-Steiner	AGN
1H0123+075	SAO109841	AC	1H0258-126	H0300-124	AGN
1H0128-139	A209	CG	1H0258-015	NGC1194	AGN
1H0129+303	M33	Misc.	1H0300-482	Maza-AGN	AGN
1H0130+473	OC+457	AGN	1H0307-722	H0307-730	AGN
1H0144+747	SAO004456	AC	1H0324-636*	EXO0305-655	AC

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NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H0310+576	Wool.9113AB	AC	1H0430-133	A496	CG
1H0311-227	EF_Eri	CV	1H0435-531	Fair_303	AGN
1H0311-348	QSO-MONCK	AGN	1H0433-088	Sy2	AGN
1H0315-445	S0316-444	CG	1H0435-274	H0439-272	AGN
1H0316+413.AB	N1275	CG+AGN	1H0437+206	SAO076708	AC
1H0323+342	H0321+340	AGN	1H0441-207	A514	CG
1H0334+291	SAO075927	AC	1H0445-060	NGC1667	AGN
2H0323+022	H0323+022	BL	1H0446+450	3C129	CG
1H0324-530	S0328-527	CG	1H0448-041	H0449-039	AGN
1H0340+392*	4C39.12	CG	1H0451-747	S154	Misc.
1H0327+000	SAO111291	AC	1H0451-560	H0449-55	AC
1H0331+257	SAO076031	AC	1H0455+276	MWC_740	XRB-Be
1H0332+317	NRAO140	AGN	1H0456+304	star	AC
1H0334+098	A0335+098	CG	3H0454+84	S4_0454+84	BL
1H0342-392	S0334-399	CG	1H0455-441	star	AC
1H0335-357	NGC1399	CG	1H0459+248	H0459+248	CV
1H0336-434	SAO216434	AC	1H0502-755	HD32918	AC
1H0337-152	H0336-152	AGN	1H0505-386	N1759	CG
1H0341-537	S0341-538	CG	1H0510+031*	AGN-GHIGO	AGN
1H0351+194	star	AC	1H0501+592	SAO025003	AC
1H0347-413	Maza-AGN	AGN	1H0506-039	EXO0506-042	BL
1H0355-116	Q0350-121	AGN	1H0509+166	H0507+164	AGN
1H0339-822	H0355-826	AGN	1H0512-401	NGC1851	XRB
1H0350-735	S0353-741	CG	1H0515-488	Cl.0513-491	CG
1H0352+308	X_Per	XRB-Be	1H0516+063	A539	CG
1H0358-669	SAO248921	AC	1H0525+340	HD242257	XRB-Be
1H0402+573	H0402+574	XRB-Be	1H0507-459	Pic_A	AGN
1H0409-078*	SAO130994	AC	1H0515-363	PKS0521-365	BL
1H0413-116	PKS0405-123	AGN	1H0521-720	LMCX-2	XRB
1H0409+102	A478	CG	1H0523-118	IR0521-122	AGN
1H0413+009	1E0414+009	BL	3H0525+340	S_Aur	AC
1H0414+380	3C111	AGN	1H0520+121	GW_Ori	AC
1H0414-551	NGC1566	AGN	1H0527-328	TV_Col	CV
1H0419+280.A	SAO076567	AC	1H0531+219	Crab_Nebula	SNR
1H0419+280.B	Nkd.TTauri	AC	1H0534-667	LMCX-4	XRB
1H0422-086	Cl0423-086	CG	1H0536+263	V725_Tau	XRB-Be
1H0419-577	H0425-573	AGN	1H0538-577	H0534-581	CV
1H0426+051	3C120	AGN	1H0538+401	star	AC
1H0427+177*	SAO094002	Misc.	3H0535-668	H0535-668	XRB-Be
1H0429-616	S0430-615	CG	1H0533+607	H0538+608	CV

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NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H0538-641	LMCX-3	XRB	1H0726-259	4U0728-25	XRB-Be
1H0543-205*	SAO170678	AC	1H0729+316	YY_Gem	AC
1H0539-226	SAO170757	AC	1H0741+651	NGC2403	Misc.
1H0540-697	LMCX-1	XRB	1H0809+796	H0731+801	AGN
1H0542-407	H0542-407	CV	3A0729+103	BG_CMi	CV
3H0544-665	LMC.trans	XRB	1H0735-372	SAO198273	XRB-Be
1H0543-289	SAO170952	AC	1H0742-566	SAO235385	AC
1H0546-439	SAO217600	AC	1H0744+499	Mkn_79	AGN
1H0547-575	SAO234181	AC	1H0741+289	s_Gem	AC
1H0548-322	PKS0548-322	BL	1H0743+037	YZ_CMi	AC
1H0551-074	NGC2110	AGN	1H0743+184	81_Gem	AC
1H0551+463	MCG-8-11-11	AGN	1H0749-554	SAO235476	AC
1H0547-601	SAO249388	AC	1H0739-529	HD63666	XRB-Be
1H0553-480	CL0555-480	CG	1H0745-191	PKS0745-19	CG
1H0556+286	HD249179	XRB-Be	1H0749-600	SAO250018	Be
1H0555-384	3A0557-383	AGN	1H0801+213	U_Gem	CV
1H0557-503	H0558-504	AGN	3H0754+39	1E0754+394	AGN
1H0555+680	star	AC	1H0753+456	H0759+452	AGN
1H0606-351	S0604-353	CG	1H0759-490	star	AC
1H0613+479	SS_Aur	CV	1H0758+762	PG0804+76	AGN
4U0601-49	LB1800	CV	1H0806-545	SAO235808	XRB-Be
1H0610+091	V1055_Ori	XRB	1H0811+625	SU_UMa	CV
1H0612+226	IC443	SNR	1H0814-073	A644	CG
1H0551-819	H0616-818	CV	1H0816+017	A653	CG
1H0620-646	H0622-645	AGN	1H0824-641	SAO250196	AC
1H0623-539	S0626-543	CG	1H0820-426	Pup_A	SNR
1H0636-403	SAO218055	XRB-Be	1H0823+301	HD72146	AC
1H0633-752	PKS0637-75	AGN	1H0823+561.A	SAO026828	AC
1H0635-431	H0640-432	AGN	1H0822+042	BL0829+046	BL
1H0646+250	e_Gem	AC	1H0823+561.B	4C55.16	AGN
1H0641+741	Mrk_6	AGN	1H0827+089.B	H0829+089	BLcand
1H0658+595.A	EXO0706+592	BL	1H0828-706	H0829-701	AGN
1H0659-494	H0707-495	AGN	1H0827+089.A	SAO116952	AC
1H0659+453	Mkn_376	AGN	1H0832+488	PG0834+488	CV
1H0709-360	H0710-360	CV	1H0833+654	pi1_UMa	AC
1H0658+595.B	H0715+594	AGN	1H0849+578	PG0849+580	CV
1H0707+443	EXO0709+443	AGN	1H0857-242	H0857-242	CV
1H0712+558	A576	CG	1H0859-403	VelaX-1	XRB
1H0713-112	SAO152714	AC	1H0908-326	T_Pyx	CV
1H0714-390	HD58111	AC			

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HEAO-1 SCANNING MODULATION COLLIMATOR
IDENTIFICATIONS OF HARD X-RAY SOURCES

NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H0906-095	A754	CG	1H1100-230	H1101-232	BL
1H0912+407.A	IRS0910+411	AGN	1H1104+382	Mkn_421	BL
1H0917-121	3C218	CG	1H1109+181	1E1114+183	CG
1H0912+407.B	NGC2844	AGN	1H1121+309.B	XI_UMa	AC
1H0918-548	X0918-549	XRB	1E1114+182	DP_Leo	CV
1H0919-312	H0922-374	XRB	1H1118-602	CenX-3	XRB
1H0920-629	X0921-630	XRB	1H1118-431	H1118-429	AGN
1H0929+122	Mrk_705	AGN	X1118-616	Wra_793	XRB-Be
1H0921+449	H0925+449	AGN	1H1120+423	PG1121+422	AGN
1H0927+501	H0928+500	CV	1H1121-591	MSH11-54	SNR
1H0932+107	Sy-Huchra	AGN	1H1121+309.A	AW_UMa	AC
1H0946-144	NGC2992	AGN	1H1130+043	T_Leo	CV
1H0946-309	A0945-30	AGN	1H1137+699	Mkn_180	BL
1H0950+696.A	M82	CG	1H1135-372	NGC3783	AGN
1H0950+696.B	NGC3031	AGN	1H1135-125	H1137-127	AGN
1H0945+252	HD86590	AC	1H1137-649	HD101379	AC
1H0951+057	RR_Sex	AC	1H1142-178	H1143-182	AGN
3H0953+415	PG0953+415	AGN	1H1142+199	A1367	CG
1H1003+428	H1002+427	AGN	1H1148-499.A	SAO222993	AC
1H1013+498	BL1011+496	BL	2A1150+72	YY_Dra	CV
1H1006-472	KO_Vel	CV	1H1144-617.A	X1145-616	XRB
1H1012-098.A	A970	CG	1H1144-617.B	V801_Cen	Be
1H1012-098.B	PKS1020-103	AGN	1H1148-499.B	SAO223029	AC
1H1017+202	NGC3227	AGN	1H1152+237	BL1147+245	BL
1H1023+513	A1004	CG	1H1139+594	star	AC
1H1017+226	H1025+220	CV	1H1148-499.C	HD103197	AC
1H1027-351	S0636	CG	1H1150+738	H1154+734	AGN
1H1032-142	H1029-140	AGN	1H1154+294	4C29.45	AGN
A1028-56	SAO238130	XRB-Be	1H1205+440	NGC4051	AGN
1H1033-273	A1060	CG	1H1208-518	PKS1208-518	SNR
1H1039-073	H1039-074	AGN	1H1210+393	NGC4151	AGN
1H1041+395	A1068	CG	1H1213+718.A	SAO007533	AC
1H1043-641	Theta_Car.	Misc.	1H1219+301.B	Mkn_766	AGN
1H1045-597	Eta_Car	Misc.	1H1211+762*	Mkn_205	AGN
1H1046+547	1E1048+542	CV	1H1213+718.B	H1218+713	AGN
1H1055+299.A	A1120	CG	1H1215-549	SAO239838	AC
1H1055+299.B	Arp.107A	AGN	1H1219+301.A	2A1215+303	BL
1H1051+607	SAO015338	AC	1H1221-623	GX301-2	XRB
1H1059+566	A1132	CG	1H1225-303	SAO203539	AC
1H1054-665	QU_Car	CV	1H1226+022	3C273	AGN

<u>TABLE 3.1</u>

HEAO-1 SCANNING MODULATION COLLIMATOR
IDENTIFICATIONS OF HARD X-RAY SOURCES

NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H1228+081	N4472	CG	1H1338-604.B	SAO252429	AC
1H1226+128	VirgoM87	CG	1H1338-604.A	X1344-604	XRB
1H1229+199	AKN_374	AGN	1H1344-326	S1344-326	CG
1H1241+626.A	1E1235+6315	BL	1H1345-300	IC_4329A	AGN
1H1253-761	SAO256967	XRB-Be	1H1348+267	A1795	CG
1H1238-599	X1239-599	XRB	1H1350+696	Mkn_279	AGN
1H1238-050	NGC4593	AGN	3A1357+626	PG1351+64	AGN
1H1249-637	SAO252002	Be	1H1341+402	Mkn_464	AGN
1H1241+626.B	Wool.star	AC	1H1359-645	Exo_Tr	XRB
1H1244-588	X1246-588	XRB	1H1359-421	PKS1355-416	AGN
1H1244-409	Cen_Cl.	CG	3H1405+804	AC+79_4347	AC
1H1251-291	EX_Hya	CV	1H1352-105.A	A1836	CG
1H1255-567	SAO240367	XRB-Be	1H1352-105.B	A1837	CG
1H1254-690	X1254-690	XRB	1H1357+033	A1835	CG
1H1255-172	A1644	CG	1H1411+094.A	SAO100840	AC
1H1241+626.C	Mrk_236	AGN	1H1358+146	Cl.1405+142	CG
1H1257-610	GX304-1	XRB-Be	1H1404-450	1E1405-451	CV
1H1257+281	A1656ComaCl	CG	1H1409-267	PKS1404-267	CG
1H1304-497	DM-48_7859	XRB-Be	1H1405+230	A1880	CG
1H1303-047	SAO139157	AC	1H1408-031	NGC5506	AGN
1H1305+466.A	A1682	CG	1H1415+255	NGC5548	AGN
1H1305+466.B	H1307+462	AGN	1H1411+094.B	SAO120406	AC
1H1308-237	NGC4968	AGN	1H1420+481	H1419+480	AGN
1H1313+363	NGC5033	AGN	X1417-624	2S1417-624	XRB
1H1312-161	NGC5044_grp	CG	1H1426+120	Cl.1422+123	CG
1H1312+393	SAO063494	AC	1H1419+584	A1925	CG
1H1321+692*	H1318+692	AGN	1H1422+273	B2_1425+267	AGN
1H1326+174	SAO100517	AC	1H1427+013	Mkn_1383	AGN
1H1318+560	H1320+551	AGN	1H1430+423	H1426+427	BL
1H1320+066	IR1321+058	AGN	1H1438-623	MSH14-63	SNR
1H1323-428	Cen_A	AGN	1H1429+370	Mkn_478	AGN
1H1326-025	SAO139320	AC	1H1448+415	H1443+421	AGN
1H1322-309	S1325-312	CG	1H1439+393	DM+39_2801	AC
1H1325-246	H1324-246	AGN	1H1444-553	H1447-554	AGN
1H1326-269	A1736	CG	1H1449+316	star	AC
1H1332-233	A1757	CG	1H1450+190.B	xi_Boo	RSCVn
1H1332+372	SAO063623	AC	1H1450+190.A	A1991	CG
1H1334-340	1E1333-340	AGN	1H1456-826	SAO258714	AC
1H1329+514	star	AC	1H1457+214.	A2009	CG
1H1338-144	H1338-143	AGN	1H1458-416	SN_1006	SNR

TABLE 3.1

HEAO-1 SCANNING MODULATION COLLIMATOR
IDENTIFICATIONS OF HARD X-RAY SOURCES

NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H1504+035	Mkn_1392	AGN	1H1634-281	tau_Sco	Misc.
1H1504+473	SAO045357	AC	1H1635-642	ClTrAustral	CG
1H1508+060	A2029	CG	1H1636-536	X1636-536	XRB
1H1510+335	A2034	CG	1H1639-109	H1643-113	AGN
1H1511-589	MSH15-52	SNR	1H1642-455	GX340+0	XRB
1H1513-400	Steiner.Syl	AGN	1H1653-062	SAO141428	AC
1H1514+072	A2052	CG	3H1646+152	S_Her	AC
1H1515+660	H1517+656	BL	1H1651+398	Mkn_501	BL
1H1516-569	CirX-1	XRB	1H1653-083	SAO141439	AC
1H1521+308.A	A2061	CG	1H1657-037	1E1654-042	AC
1H1518+282	A2065	CG	1H1656+354	HerX-1	XRB
1H1521+083	A2063	CG	1H1658-298	X1658-298	XRB
1H1521+308.B	H1522+307	AGN	1H1659-487*	GX339-4	XRB
1H1530+585	Mrk_290	AGN	X1657-415	E1657-415	XRB
1H1538-522	X1538-522	XRB	1H1702-363	GX349+2	XRB
1H1538-182	AGN-Steiner	AGN	1H1702+336	A2244	CG
1H1540+338	H1537+339	AGN	1H1703-013	UGC10683B	AGN
1H1543-624	X1543-624	XRB	X1700-377	V884_Sco	XRB
1H1544+360	A2124	CG	X1702-429	X1702-429	XRB
1H1555-552	SAO243098	XRB-Be	1H1702-437	X1705-440	XRB
1H1556-605	2S1556-605	XRB	1H1704+605	3C351	AGN
1H1556+273	A2142	CG	1H1705-250	Nova_Oph77	XRB
1H1604+158	A2147	CG	1H1706+241	HD154791	Misc.
1H1607-189	SAO159731	AC	1H1706+786	A2256	CG
1H1608-522	X1608-522	XRB	1H1702+456	star	AC
1H1613-097	H1613-101	AGN	1H1708-405	X1708-407	XRB
1H1613-060	A2163	CG	1H1712-337	X1711-339	XRB
1H1615+655	Mkn_876	AGN	1H1712+490.A	SAO046541	AC
3H1613+075	SAO121460	AC	4U1708-23	OphiucusCl	CG
1H1611-286	SAO184320	AC	1H1712+641	A2255	CG
1H1617-155	ScoX-1	XRB	1H1715-321	X1715-321	XRB
1H1626-245*	rho_Oph	Misc.	1H1720-669	SAO253856	AC
1H1622-751	WW_Aps	AC	1H1712+490.B	Arp_102B	AGN
1H1624-490	X1624-490	XRB	1H1714+424	PG1717+413	CV
1H1627-673	X1627-673	XRB	1H1718-010	3C353	CG
1H1631+394	A2199	CG	1H1719+033	SAO122313	AC
1H1626+058	A2204	CG	1H1720+269.B	HRI1718+266	CG
1H1627+302	QSO1629+299	AGN	1H1718+242	V396_Her	AGN
1H1630+673*	Mkn_885	AGN	1H1720+117*	H1722+119	BL
4U1630-472	X1630-472	XRB	1H1720+269.A	A2263	CG

TABLE 3.1

HEAO-1 SCANNING MODULATION COLLIMATOR
IDENTIFICATIONS OF HARD X-RAY SOURCES

NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H1727+308	Mkn_506	AGN	1H1828-105	G21.5-1	SNR
1H1728-213	Kepler_SNR	SNR	1H1840+729	QSO1831+731	AGN
1H1730+500	IZw187	BL	1H1828-593	Fair_49	AGN
X1724-307	Terzan_2	XRB	1H1832-652	ESO103-G35	AGN
1H1728-334.A	GX354-0	XRB	1H1835+326	3C382	AGN
1H1728-334.B	Liller_1	XRB	1H1836-786	H1839-786	AGN
1H1728-247	GX1+4	XRB	1H1837+049	SerX-1	XRB
1H1728-169	GX9+9	XRB	1H1840-050	G27.4+0	SNR
1H1735-444	X1735-444	XRB	1H1845-024.B	G29.7-0.	SNR
1H1739+744	SAO008842	AC	1H1845-024.A	X1845-024	XRB
1H1735+400	A2278	CG	1H1858+797	3C390.3	AGN
1H1739-126	H1739-121	AGN	1H1850-087*	NGC6712	XRB
1H1741+586	NGC6418	AGN	1H1853-312	V1223_Sgr	CV
1H1740+329	B1742+330	CG	1H1852+015*	G34.7-0	SNR
1H1744-293	X1742-294	XRB	1H1903+689	H1907+690	CV
1H1744-265*	GX3+1	XRB	1H1905+000	X1905+000	XRB
1H1746-370	NGC6441	XRB	1H1909+096*	X1907+097	XRB-Be
1H1747+675	H1746+676	AGN	1H1909+304	SAO067836	AC
1H1748+685	KAZ_163	AGN	1H1907+074	X1908+075	XRB
1H1746+475	H1750+477	AGN	1H1908+047	SS433	SNR
1H1752+289	SAO085590	AC	1H1913-193	H1914-194	BL
1H1754-338	X1755-338	XRB	1H1911-589	ESO141-G55	AGN
1H1752+081	H1758+081	CV	1H1916-053	X1916-053	XRB
1H1758-250	GX5-1	XRB	1H1918-481	BN_Tel	AC
1H1758-205	GX9+1	XRB	1H1919+438	A2319	CG
1H1758-482	SAO228707	AC	1H1926+713	YZ_Dra	AC
1H1811+670	V1803+676	AGN	1H1922+746	4C73.18	AGN
1H1803+696	3C371	BL	1H1930-589	Cape-Ed.CV	CV
1H1801+579	star	AC	1H1936+541	DM+53_2262	XRB-Be
1H1811-171*	GX13+1	XRB	1H1927-516	H1934-513	AGN
1H1812-182	G12.0-0	SNR	1H1929+509	H1933+510	CV
1H1815+538.B	H1811+540	AGN	1H1930+302	G65.2+6	SNR
1H1813-140	GX17+2	XRB	1H1934-063.A	H1934-063	AGN
1H1814+498	AM_Her	CV	1H1939-405	V2153_Sgr	AC
1H1815-121	X1812-121	XRB	1H1934-063.B	HD185510	AC
1H1815+538.A	SAO030826	AC	1H1937-106*	NGC6814	AGN
1H1820-303	NGC6624	XRB	1H1950-552	S1948-552	CG
1H1820+643	KUV_1821+64	AGN	1H1958+325	3A1954+319	XRB
1H1822-371	X1822-371	XRB	1H2010-697	BQ_Pav	AC
1H1822+000	X1822-000	XRB	1H1956+115	X1957+115	XRB

TABLE 3.1

HEAO-1 SCANNING MODULATION COLLIMATOR
IDENTIFICATIONS OF HARD X-RAY SOURCES

NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H1956+350	CygX-1	XRB	1H2207+455	SAO051684	AC
1H1958+406	Cyg_A	CG	1H2209-470	NGC7213	AGN
1H2004+729	H2001+725	AGN	1H2205+538	4U2206+54	XRB-Be
1H2006+646	HRI2003+642	AC	1H2218+197*	PG2209+184	AGN
1H2016+772	S5_2007+77	BL	1H2207+268	Wool.star	AC
1H2012-567	S2008-569	CG	1H2207+829	SAO003716	AC
1H2018-529	Fair_341	AGN	1H2217-392	star	AC
1H2018+439	HD193793	Misc.	H2215-086	FO_Aqr	CV
1H2018+366	EXO2030+374	XRB	1H2221-017.A	A2440	CG
1H2030+407	CygX-3	XRB	1H2221-017.B	3C445	AGN
1H2034+734	SAO009779	AC	1H2214+589	3G71	XRB-Be
1H2031-330	AT_Mic	AC	1H2236-372.A	S2231-379	CG
1H2041+756	SAO009828	AC	1H2236-372.B	EXO2231-379	AGN
1H2041-108	Mkn_509	AGN	1H2236+497	SAO052073	AC
1H2044-032.A	Mrk_896	AGN	1H2226-269	NGC7314	AGN
1H2102-796	SAO258871	AC	1H2238-123	Mkn_915	AGN
1H2044-032.B	A3.QSO	AGN	1H2229-542	SAO247577	AC
1H2050+310	Cyg.Loop	SNR	1H2239+294	AKN_564	AGN
1H2107-097	H2106-099	AGN	1H2240-480	CompactGrp	CG
1H2108+019	Zwicky_gal.	CG	1H2245-646	S_2246-646	CG
1H2118-342	WMR-CV	CV	1H2251+450	EV_Lac	AC
1H2109+818	SAO003536	AC	1H2251-179	MR2251-178	AGN
1H2120+184	HRI-SAO	Misc.	1H2251+167	SAO108231	AC
1H2124-529	HD204128	AC	1H2251-035	AO_Psc	CV
1H2128+120	M15	XRB	1H2252+621	IPC_Blob	Misc.
1H2121-584	SAO247096	AC	1H2256+057	A2507	CG
1H2131+473	X2129+470	XRB	1H2258+585	G109.1-1.0	SNR
1H2129-624	H2132-626	AGN	1H2301+086	NGC7469	AGN
1H2140+433	SS_Cyg	CV	1H2303-089	Mrk_926	AGN
1H2142+380	CygX-2	XRB	1H2303+039	PG2304+042	AGN
1H2148-200	A2384	CG	1H2315+257	SAO091019	AC
1H2150+171	A2390	CG	1H2251-710	HD219025	AC
1H2156-304	PKS2155-304	BL	1H2307-222.A	A2556	CG
1H2158-602.B	S2154-606	CG	1H2307-222.B	A2554	CG
1H2158-602.A	S2158-602	CG	1H2315-423	NGC7582	AGN
1H2202+501	SAO051568	XRB-Be	1H2319+188	A2572	CG
1H2214-313	NGC7172	AGN	1H2313+783	SAO010697	AC
1H2158+046	PKS2201+04	BL	1H2322-269*	SAO191840	AC
1H2206-052	A2415	CG	1H2318+417	H2321+419	BLcand
1H2213+484	SAO051628	AC	1H2319-582	H2320-582	AGN

TABLE 3.1

HEAO-1 SCANNING MODULATION COLLIMATOR
IDENTIFICATIONS OF HARD X-RAY SOURCES

NRL NAME	ID	TYPE	NRL NAME	ID	TYPE
1H2320+084	NGC7674	AGN			
1H2320+146	A2593	CG			
1H2321+585	Cas_A	SNR			
1H2323+165	A2589	CG			
1H2327-170	DM-176768	AC			
1H2337+701	SAO010779	AC			
1H2336+462	SAO053204	AC			
1H2343+090	A2657	CG			
1H2348-281	S2345-284	CG			
1H2352+109	A2675	CG			
1H2354+285	SAO091578	AC			
1H2351-315.B	H2354-307	AGN			
1H2355-350	PKS2354-35	CG			
1H2353-177	star	AC			
1H2351-315.A	H2356-309	BL			

4 Guest Collaborator Program

Long before the HEAO-1 launch we realized that the primary scientific return of the MC experiment would not be the plots of allowed x-ray source locations in celestial coordinates, but rather would be the publication of each astronomical identification, with appropriate discussion of the physical characteristics of the system. It was obvious this must involve extensive participation by many astronomers outside of our MC x-ray experiment team. Well planned, deliberate studies were needed to make significant progress.

We perceived some major differences from the traditional Guest Investigator programs being set up for both the HEAO-1 and HEAO-2 missions. Accessing and analyzing raw x-ray data is not generally a task in which an optical astronomer is skilled or interested. HEAO-1 was originally defined as a six month, solely PI mission, and the MC data system, designed in the 1974 to 1976 time frame, was intended for operation only by computer specialists guided by the MC experiment scientific team. The baseline HEAO-1 mission was a six month all-sky scan without pointing, so that 4 to 8 full days of the real-time telemetry stream must be processed for each source position. The key fact is that essentially all astronomers are interested in particular types of objects, whereas a priori the identification type of an arbitrary, weak x-ray source cannot be anticipated.

Therefore we initiated an active Guest Collaborator Program. (Einstein used a similar collaborative program for their identifications of deep and medium survey sources, cf. Giacconi et al. 1979). In this program we freely collaborated with any astronomer in the world on specific x-ray identifications according to their interests. Typically, they provided detailed or repeated spectra, polarization, photometry, and astronomical interpretation, after our indication of the identification type. Their data might be in any electromagnetic band: optical, ultraviolet, infrared, radio, or x-ray.

Table 4.1 provides details on the collaborations which resulted in publications. People from CfA and MIT are only listed during periods of time when they were not actually employed on the MC project. Several of these people have worked on more than one publication, and each publication has many co-authors. We have additional publication with 10 other members of the HEAO-1 A-1, A-2, and A-4 teams.

We effectively organized and carried out a substantial guest observer program, at no additional cost to NASA.

Table 4.1
HEAO-1 A-3 GUEST COLLABORATORS

Observer	Institution	Observatory
P.A. Charles J. Thorstensen	University of California, Berkeley	Lick, CTIO
D. Crampton	Dominion Astrophysical Observatory	DAO
M. Davis J. Huchra	Center for Astrophysics	SAO (Mt. Hopkins)
J. Grindlay C. Canizares J. McClintock	Center for Astrophysics M.I.T.	CTIO, KPNO, McGraw Hill
A. Longmore D. Malin	Royal Observatory, Edinburgh	UK Schmidt (Australia)
W. Liller	Center for Astrophysics	CTIO
B. Margon	University of California, Los Angeles	Lick
S. Mayo J. Whelan B.A. Cooke I. McHardy	Institute of Astronomy University of Leicester	AAT, RGO
P. Murdin	Anglo-Australian Observatory	AAT
S. Tapia	University of Arizona	Steward Observatory
R.M. Thomas J. Greenhill D. Watts	University of Tasmania	AAT
J. van Paradijs	MIT, University of Amsterdam	ESO
M. Ward J.C. Blades A.S. Wilson	Institute of Astronomy Anglo-Australian Observatory University of Maryland	AAT, Mt. Stromlo KPNO
S. Baliunas J. Tonry	Center for Astrophysics	Mt. Hopkins

Observer	Institution	Observatory
D.Q. Lamb W. Tucker	Center for Astrophysics	(Theoretical)
A. Lawrence I.M. McHardy J.P. Pye M. Watson	University of Leicester	Ariel V X-ray satellite
J. Steiner	Center for Astrophysics and Brazilian Astrophysical Observatory	CTIO and Brazilian Astrophysical Observatory
F.J. Jablonski I.C. Busko	Brazilian Astrophysical Observatory	1.6m telescope at B.A.O.
A.P. Cowley J.E. Hesser	Herzberg Institute. Dominion Astrophysical Observatory	DAO
M.S. Burkhead	Indiana University	Goethe Link
W.A. Dent	University of Massachusetts	Haystack Radio Observatory
A.G. Smith	University of Florida	Rosemary Hill
M. Elvis G. Fabbiano	Center for Astrophysics	IUE
G. Koenigsberger J. Swank	Goddard Space Flight Center	OSO-8
L. Petro R. Remillard	Massachusetts Institute of Technology	McGraw-Hill
C. Price	University of Michigan	McDonald Observatory
G.A. Williams	University of Michigan	McGraw-Hill
R.L. Brown	N.R.A.O.	VLA
M. Ulmer	Northwestern University	Kitt Peak, VLA
R. Cruddace	Naval Research Lab	Kitt Peak

Observer	Institution	Observatory
G. Ricker	M.I.T.	NASA IRTS, Mauna Kea
I. Tuohy D. Buckley R. Brissenden G.V. Bicknell	Australian National University	AAT, MSSSO
E. Feigelson J. Schmelz	Penn State University	VLA
R.S. Warwick	University of Leicester	Ariel V X-ray Satellite
B. Geldzahler K. Johnston P. Hertz	Naval Research Lab	VLA
W. Romanishin S. Wyckoff P.A. Wehinger	Arizona State University	Kitt Peak
W.P. Blair	John Hopkins	IUE
J.-P. Caillault	University of Georgia	Kitt Peak
D.J. Sullivan	Victoria University of Wellington, NZ	MSSSO, MJUO
M. Clark	Mount John University Observatory	MJUO

5 Publications

5.1 Articles

1978 The scanning modulation collimator experiments on HEAO-1 (D.A. Schwartz, J. Schwarz, H. Gursky, H.V. Bradt, and R.E. Doxsey). In *Proceedings of the American Institute of Aeronautics and Astronautics*, 16th Aerospace Sciences Meeting, Huntsville, Alabama, paper 78-34.

1978 Location of the Norma Transient with the HEAO-1 Scanning Modulation Collimator (G. Fabbiano, H. Bradt, R.E. Doxsey, H. Gursky, D.A. Schwartz, and J. Schwarz). *Astrophysical Journal (Letters)*, volume 221, L49.

1978 Position for the Rapid Burster MXB 1730-335, Determined with the Scanning Modulation Collimator on HEAO-1 (R. Doxsey, H. Bradt, H. Gursky, M. Johnston, D.A. Schwartz, and J. Schwarz). *Astrophysical Journal (Letters)*, volume 221, L53.

1978 Nova Ophiuchi 1977: An x-ray nova (R.E. Griffiths, H. Bradt, R. Doxsey, H. Friedman, H. Gursky, M. Johnston, A. Longmore, D.A. Malin, P. Murdin, D.A. Schwartz, and J. Schwarz). *Astrophysical Journal (Letters)*, volume 221, pages L63-L67.

1978 The X-Ray Light Curve of Nova Ophiuchi 1977 (H1705-25) (M.G. Watson, M.J. Ricketts, and R.E. Griffiths). *Astrophyscial Journal (Letters)*, volume 221, L69.

1978 Measurement of x-ray source positions by the scanning modulation collimator on HEAO-1 (H. Gursky, H. Bradt, R. Doxsey, D.A. Schwartz, J. Schwarz, R. Dower, G. Fabbiano, R.E. Griffiths, M. Johnston, R. Leach, A. Ramsey, and G. Spada). *Astrophysical Journal*, volume 223, 973.

1978 Position and pulse profile of the x-ray transient 4U0115+63 (M. Johnston, H. Bradt, R. Doxsey, D. Schwartz, and J. Schwarz). *Astrophysical Journal (Letters)*, volume 223, L71.

1978 Identification of 4U1651+39 with the BL Lac object Markarian 501 with the modulation collimator on HEAO-1 (D.A. Schwartz, H.V. Bradt, R.E. Doxsey, R.E. Griffiths, H. Gursky, M.D. Johnston, and J. Schwarz). *Astrophysical Journal (Letters)*, volume 224, L103.

1978 LMC X-1, X-2, X-3: precise positions from the HEAO-1 modulation collimator (M.D. Johnston, H.V. Bradt, R.E. Doxsey, H. Gursky, D.A. Schwartz J. Schwarz, and J. van Paradijs). *Astrophysical Journal (Letters)*, volume 225, L59.

1978 Location of the pulsating binary x-ray source 4U1538-52 with the HEAO-1 scanning modulation collimator (D.A. Schwartz, H. Gursky, J. Schwarz, H. Bradt, and R. Doxsey). *Nature*, volume 275, 517.

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Appendix A: Descriptionof the MC Experiment

APPENDIX A

We summarize here a review of the scanning modulation collimator hardware and data processing. This appendix is reproduced from sections 1.2 and 1.3 of our proposal P1192-6-82 of June 1982, to NASA, to "Preserve the Scientific Data Base of the HEAO-1 Scanning Modulation Collimator (MC) Experiment."

A-1 Description of the Experiment Hardware

The MC instrument contained two modulation collimator banks, each a stack of four planes of wire grids. Each grid was a set of regularly spaced wires, with the spaces nominally equal to the wire diameters. In a four-grid collimator (cf. Bradt et al. 1968), the acceptance of the outer grid pair has a repeating triangular pattern. Each of the two inner grids shadows every other remaining triangle (i.e., reduces their response to zero) so that the overall acceptance pattern, as a function of the azimuth angle in a plane perpendicular to the wires, is a set of triangles of half-width δ and spaced 8 apart. On-orbit

The instrument also contained two image dissector star cameras, rigidly mounted to the same optical bench as the modulation collimators. Along with rate integrating gyro data from the spacecraft, we used our star camera data and the Smithsonian Observatory catalogue of star positions to calculate the instantaneous field of view on the celestial sphere.

The experiment functioned flawlessly on-orbit, except for the failure of one of the four proportional counters in MC2 after about 3 weeks. This degraded the MC2 area to 300 cm^2 for most of the mission. Throughout the mission, no changes in our aspect or alignment parameters occurred.

There is a systematic aspect displacement with elevation that has been calibrated to be about 4 arcsec per degree in elevation from the scan plane. This correction is applied by the software which sums data from different scans.

Published descriptions of the experiment hardware appear in Roy et al. (1977), Gursky et al. (1978), and Schwartz et al. (1978).

A-2 Data Reduction and Analysis

Figure 2 shows a schematic block diagram of our data reduction programs. Although we processed quick look data to monitor the experiment and obtain some science results, the same data was reduced sequentially when received as a production data tape; therefore, only production data is relevant to this proposal. The key "scientific" steps are the calculation of the calibration gives δ_1 = 28.86 arcsec for the "30 arcsec" collimator (MC1) and δ_2 = 115.61 arcsec for the "2 arcmin" collimator (MC2). In addition to the grids each has an egg-crate collimator which limits the overall field of view to 7°.6 x 7°.6, full width at zero response. The net open area on-axis was about 400 cm^2 per collimator.

The grid wires of MC1 and MC2 are respectively tilted -10°.265 and +9°.821 with respect to the spacecraft scan circle. The egg-crate collimator is aligned parallel and perpendicular to the scan. Figure 1 shows the collimators' responses to Sco X-1. One second of time represents 0°.2 in scan angle. The figure illustrates the 30" and 2' FWHM response, the 4' and 16' spacing between triangles, and the coarse collimator envelope.

Four sealed proportional counters, behind each modulation collimator, sort X-ray events into three channels with pulse height boundaries equivalent to 0.9-2.6, 2.6-5.4, and 5.4-13.3 keV. The overall spectral response is defined by the 2.5 micron thick mylar thermal shield and 43 micron thick Be window to be above about 1.5 keV (10% quantum efficiency), and by the filling gas of 855 mm argon and 70 mm CO_2 to be below about 16 keV. The total counts from MC1 and MC2 in 0.040 and 0.160 second intervals, respectively, are telemetered. At the nominal scan rate, these correspond to angles of 5 and 20 arcsec, in MC1 and MC2 respectively. Pulse shape discrimination (PSD) is used to reject non-X-ray events, and the PSD and other auxiliary rates are telemetered.

Sco X-1 AS SEEN BY SCANNING MODULATION COLLIMATOR
7 OCTOBER 1977

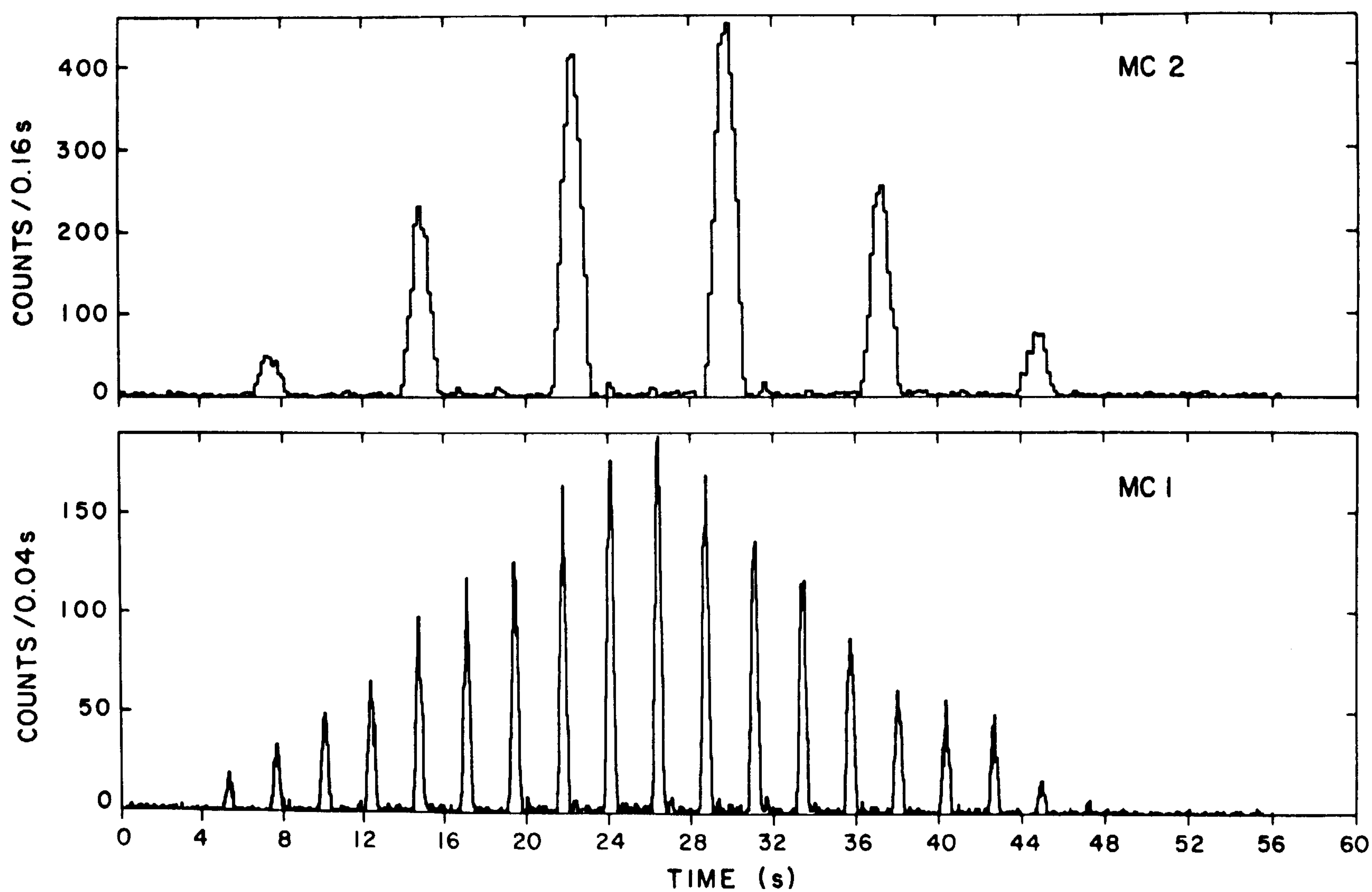


Figure 1

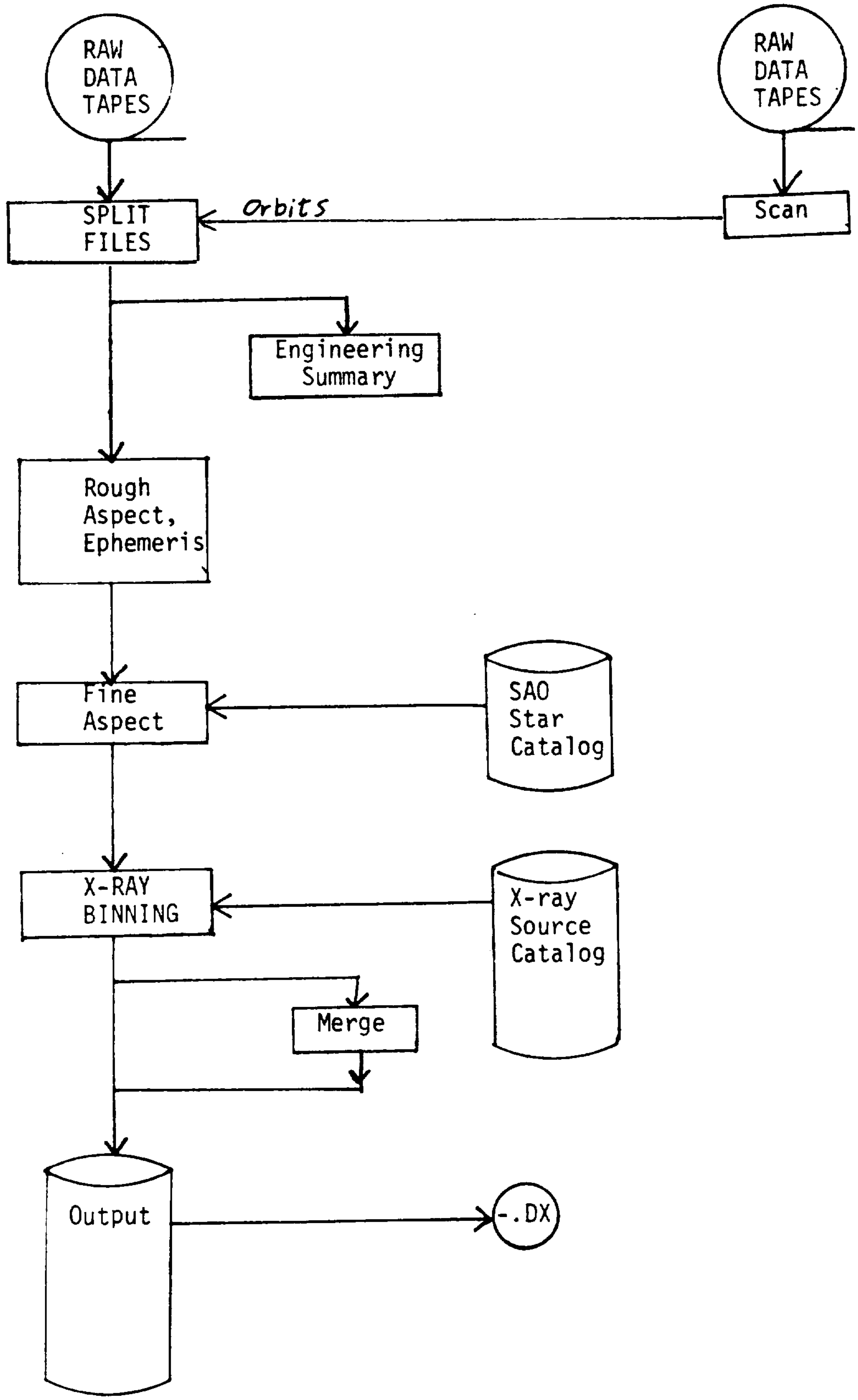


Figure 2

MC DATA REDUCTION

"fine aspect" solution, and the binning of the X-ray data. The aspect solution is merely an intermediary used to bin the X-ray data. We will document it further with our data submission, but need not discuss it here. However, understanding the X-ray binning procedure is prerequisite to understanding what scientific data base is practical and meaningful for delivery to the NSSDC.

We will discuss the 30 arcsec collimator (MC1) in detail. For MC2, multiply all sample times and angles by 4. We read out the total counts in each pulse height channel every 40 milliseconds. This corresponds to about 5 arcsec perpendicular to the modulation collimators at the nominal spacecraft scan rate of 0.2 deg/sec; i.e., (0.040 seconds) x (0.2 deg/second) x sin 10° = 0.0014 degrees = 5 arcsec. If we had tried to bin all the X-ray data we would have required (3600 arcsec/degree) x (360 degrees/circle) x (2 circles/day) x (182 days/sky scan)/(5 arcsec/bin) = 9.4×10^7 bins on the sky, times (3 energy channels + 1 exposure time array) = 3.8×10^8 total bins. (Add 25% to account for MC2.) In terms of 1974 technology, and our available computer hardware and programming resources, this was a preposterous number. However, since our investigation proposed only to locate (and not to discover) cosmic X-ray sources; i.e., sources known to exist, it was obvious that we need only bin our X-ray data in the relatively small sky regions around each X-ray source in some catalogue.

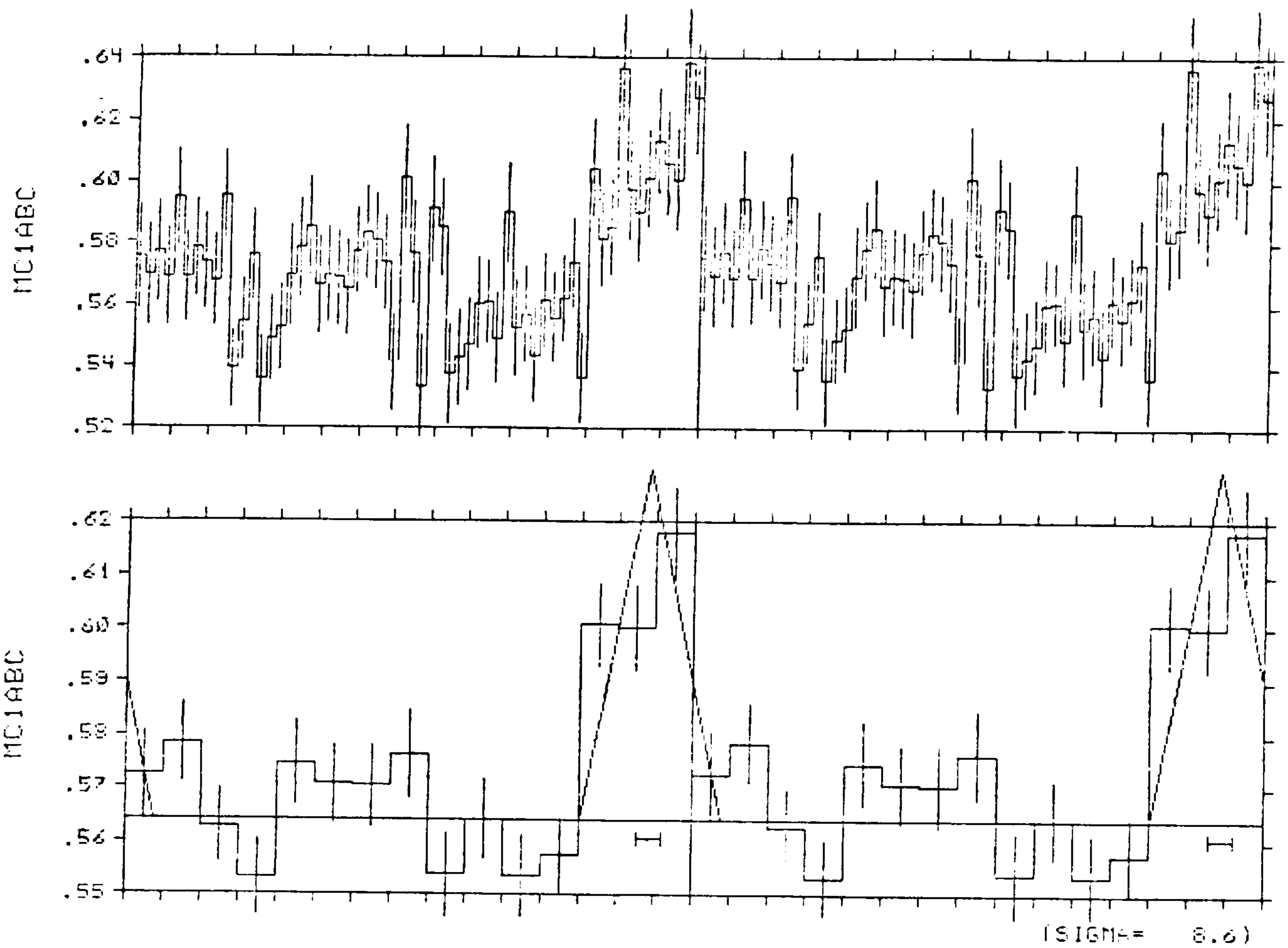
As a complication, the successive 30 minute spacecraft rotations did not precisely reproduce a single scan circle. To handle this rigorously within the general motions allowed by the spacecraft specification would have required a two-dimensional binning approach. Instead, our binning preserves each rotation individually, along with parameters, the "jitter angles", which allow superposition in later analysis. We thus bin in one dimension only, each bin representing 1/60 of the periodicity of the modulation collimator response. The approximations inherent in this scheme cause the X-ray signal to begin to wash out when the true source position is more than $\pm 1^\circ$ from the trial binning position. Therefore we often insert multiple trial binning positions for one X-ray source, if its previous location is not established to better than a 1° radius in any direction.

Another complication is that most X-ray sources are quite variable in time, at least potentially. Therefore we could not use a predetermined, fixed catalogue for our binning. At launch we did have a master X-ray source catalogue (MCAT) containing all published X-ray sources, plus private and pre-print data from experiments at MIT (OSO-7 and SAS-3), SAO (the fourth Uhuru catalogue), and the University of Leicester (the Ariel V Sky Survey Instrument, or 2A, catalogue). During our first reduction effort we added sources which we noted in the A-1 raw data, which was generously provided to us by Dr. H. Friedman of NRL in order to reduce our multiple source positions. Subsequent to the end of the mission, in February 1979, we created a new binning catalogue (BCAT), utilizing all the A-1 data which we had, plus published and some private A-2 results on new sources, and a pre-publication version of the final Ariel V catalogue (3A). One major limitation of our use of A-1 data was that we could not superpose it perpendicular to the scan circle. We therefore had lines of position up to 8° in length, along which we defined multiple binning positions. BCAT contained about 1200 positions, representing an estimated 600 distinct sources, with an estimated number of 400 above the A-3 sensitivity threshold of roughly 1 Uhuru flux unit. (1UFU = 1.7 x 10^{-11} ergs $cm^{-2} s^{-1}$, 2-6 keV; ≅ 1.6 μJy at 3.6 keV.)

As a simplification and for further compression, we "fold" the data modulo the 4 or 16 arcmin periodicity of each collimator. In Figure 1 all the triangles would be added together to form a single triangle, plus flat background, for each collimator. Figure 3 illustrates the data after folding.

The structure is 60 angular bins of size 4 arcsec and 16 arcsec for MC1 and MC2, respectively, representing the mean phase of the modulation collimator relative to the binning position during the data integration time. The raw counts in each of the three energy channels, and the integer number of readouts (in units of the integration times of 40 msec and 160 msec for MC1 and MC2, respectively) are incremented accordingly.

During the spacecraft "pointed" mode one target remains within the field of view for an extended period of time (except for earth occultations). For HEAO-1 the pointings have a very



2A0311-227
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RA: 47.9099 DEC: -22.7800
JITTER: MEAN: 236.2783 RMS: .0000
MIN: .0000 MAX: .0000

FIGURE 3

19:40:17 12/15/1978

coarse deadband of $\pm 1/2^{\circ}$, and the rates within that deadband are not controlled. The jitter of the spacecraft in response to magnetic, gravity gradient, and aerodynamic torques causes an X-ray source to be swept through the full modulation cycle of the collimators. The data reduction proceeds largely as in the case of scanning with two principal exceptions. First, the records during which data is folded are set at exactly 64 seconds (200 minor frames) instead of being one spacecraft rotation. Second, the PSD data is sorted into a parallel binning structure and those files are saved to be used in the data analysis.

The time resolution of the binned, scanning data is the 30 minute rotation period. We have lost time resolution in the 2 to 20 second range by folding modulo the collimator periodicities. For both pointing and scanning data we still preserve some information on variability in the 40 to, say, 640 millisecond range, because these are the time intervals between the successive angular bins.

Figure 4 shows a schematic block diagram of our data analysis computer programs. Data analysis is discussed in more detail in Part II. We include it here to guide scientists who may wish to use our reduced data base, and because we propose that it is the analyzed data, to the extent available, which most economically contains the meaningful and useful flight data.

The key feature of data analysis is that each modulation collimator gives a regularly spaced set of lines, with 8δ (4 or 16 arcmin) separation. The two sets of lines intersect at

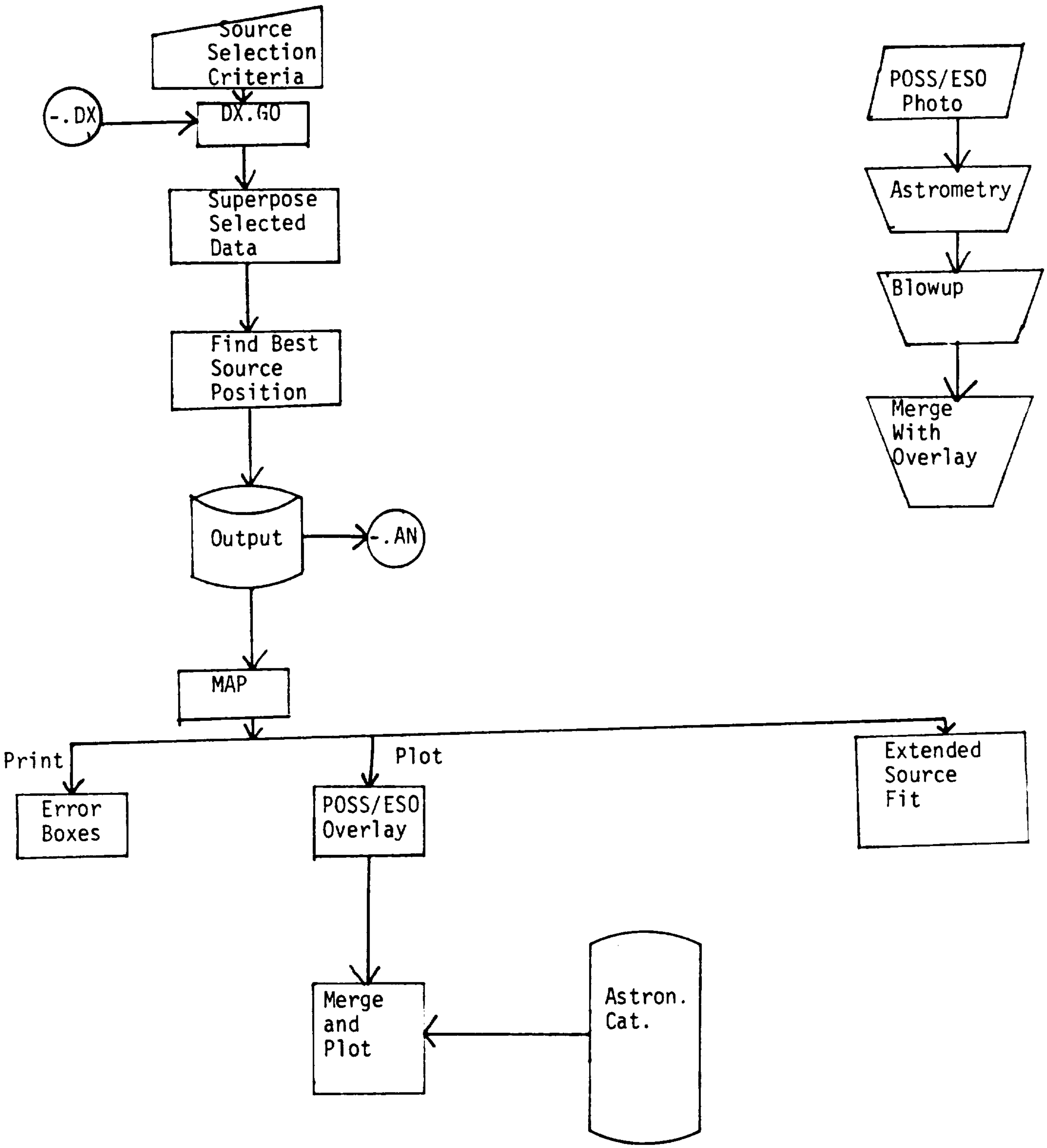

Figure 4

MC DATA ANALYSIS

20° angles, forming a regular grid of "diamonds" which contain the true X-ray source position, to better than 90% confidence. To the eye, this grid appears almost rectangular with spacing of 15 by 11 arcmin. We can almost always use either the A-1 data provided to us, or the forthcoming A-1 catalogue (made available to us in October 1981) as well as any other previous error locations, to reduce the possible locations to one or two rows of diamonds.

A key feature of data analysis is the fact that non-X-ray background sampling is interspersed with the X-ray source signal, as shown in Figure 1. Effectively, each collimator is a narrow band receiver, where the frequency is known _a priori_ and it is our measurement of the phase which relates the set of lines to the celestial sphere. This makes the modulation collimator an extremely "clean" instrument. In the case of pointed data, we use the binned PSD data to "flatten" apparent angular structure in our X-ray data which in reality arises from temporal variations in the non-X-ray background (cf. Dower et al. 1980).