Final Technical Report
For NASA Grant NAG-8-758

John A. Nousek

February 26, 1993

This report describes the activities at Penn State University supported by NASA Grant NAG-8-758. Initiated at Penn State in Jan., 1989, the goal of this program was to preserve the results of the HEAO-1 mission by transforming the obsolete and disorganized data products into modern and documented forms. The work to do this was carried out under the direction of Dr. John Nousek of Penn State University as PI, Ms. Vida Farwana and Mr. John Doren as programmers, and Dr. Richard Fink and Mr. Ralph Kraft as grad students who carried out the detailed numerical and computational algorithm development.

The result of this effort has been an archive of top level data products, totalling 70 Mbytes; an general User's Guide to the archive, which is attached to this report; and a hardcopy archive containing standardized plots and output of fits made to all the pointing data taken by the HEAO-1 A-2 LED experiment.

A more detailed description of these activities is found in the following sections. Accompanying this document is a copy of the User's Guide which may provide additional detail.

1 Overview of Mission and Project

When it was launched (1977) the first High Energy Astrophysical Observatory satellite (HEAO-1) tremendously expanded the available amount of X-ray data about the astronomical universe. With a suite of detectors that spanned the energy range from 100 eV to 10 MeV, and scanning the entire sky to far greater sensitivity levels than possible before, HEAO-1 literally opened a new window onto the heavens.

During their period of operation the instruments conducted a unique, broad spectrum survey of the entire sky. ROSAT (0.1-2 keV) and GRO (>100 keV) have surpassed the HEAO-1 sensitivity, but not over the same width of bandpass. Even where the HEAO-1 sensitivity limits are surpassed, the data remain an invaluable archive for monitoring temporal changes in the brightness and spectrum of sources.

Naturally the entire data set collected by HEAO-1 now resides at the National Space Science Data Center (NSSDC). However, the mere archiving of data and catalogs does not truly address the needs of the practicing astronomer. In practice if the tools for accessing the data and the documentation of what the data actually means and how it was collected are absent then the data become useless.

The original data processing and analysis for HEAO-1 was based on the pure Principal Investigator (PI) model in use when the mission was carried out. Data were returned to the PI team, who had sole responsibility for the use and analysis of that data. The PI team then planned software and analysis procedures which were suitable for the limited period of time after data receipt for which the mission funded data analysis (typically 3-5 years). Outside investigators were able to work on data by special arrangement with the PI team, and were expected to learn the PI specific software or relied on PI team members to perform the analysis (typically by forming collaborations leading to publications).

NASA extended the accessibility of the HEAO-1 data by continuing support for the PI groups at progressively lower funding levels. At the last year's level of funding the maintenance of the expertise is at a minimum feasible level commensurate with maintaining even a single partially funded individual at each PI team.

In 1988 a working group developed a comprehensive assessment of data holdings and analysis management entitled the 'NASA Astrophysics Data System Study'. It recognized this problem and recommended the establishment of Science Archive Research Centers. At such centers the overhead of maintaining expertise and supporting archival databases could be shared amongst several missions, allowing a yet more extended useful life.

Ideally the entire data set and all analysis and reduction software should be developed with this eventual transfer in mind. Unfortunately the HEAO-1 system was nearly as far from this ideal as it could possibly be. Software and data products were produced at a half dozen institutions, all utilizing different computing hardware and software, all formatting and storing their data in different ways.

In 1989 John Nousek of Penn State University received funding (this project, NAG-8-758) to perform the necessary migrations of data and software from the PI teams into a framework consistent with modern archival media, and modern software environments. As the total funding over the entire three year period totalled only $200,000, and five different software archives needed to be created and saved, it became imperative to adopt a 'triage' approach to saving data. Work was done immediately upon the most important data sets, and the transfer of data from perishable deteriorating magnetic tapes. Only conceptual planning was done for the lower priority data. Certain low level data products with poor or non-existant documentation were written off as hopeless.

A list of the deliverables included are listed in the next section.

2 Delivered Data Products

A-1 Experiment Machine readable version of the A-1 source catalog (Wood *et al.*).

Machine readable documentation for the A-1 source catalog.

Single day scan maps of the sky intensity seen by A-1.

Narrative description of the A-1 experiment.

A-2 LED Experiment Machine readable version of the A-2 LED source catalog (Nugent *et al.*).

Machine readable documentation for the A-2 LED source catalog.

All sky maps of the sky intensity seen by A-2 LED, in both Aitoff projections and as intensity vs. scan angle and Day number.

Spectral data files and spectral fit parameters from every LED pointing during the entire mission. [The formulation of these data has been specially chosen to make LED results in a format compatible with, and accessible by the EXOSAT database system in use at Goddard and ESTEC.]

Narrative description of the A-2 LED experiment.

WORM optical disk copy of entire A-2 LED data set in raw form.

Bibliography of the papers written using the A-2 LED experiment.

A-2 MED/HED Experiment Machine readable version of the A-2 MED/HED source catalog. (Piccinotti *et al.*).

Machine readable documentation for the A-2 MED/HED source catalog.

All sky maps of the sky intensity seen by A-2 MED/HED, in both Aitoff projections and as intensity vs. scan angle and Day number.

Narrative description of the A-2 MED/HED experiment.

A-3 Experiment Machine readable version of the A-3 source identification catalog (Remillard *et al.*).

Machine readable documentation for the A-3 catalog.

Narrative description of the A-3 experiment.

WORM optical disk copy of entire A-3 data set in raw form.

A-4 Experiment Machine readable version of the A-4 source catalog (Gruber, private communication).

Machine readable documentation for the A-4 source catalog.

All sky maps of the sky intensity seen by A-4, in both Aitoff projections and as intensity vs. scan angle and Day number.

Narrative description of the A-4 experiment.

Bibliography of the papers written using the A-4 experiment.

Archiving Documentation and Software Documentation describing the HEAO-1
archive, including the data content, directory structure, sources and other pertinent information.

Software and documentation allowing the projection of scan angle vs. Day number onto local tangent plane images or global Aitoff images.

INGRESS SQL format data table forms of the catalogs listed above, with four forms of documentation files for each catalog (general description, list of fields, database template, and scientific examples)

3 Supporting and Ancillary Activities

In addition to the HEAO-1 archive materials described above the Penn State activity has remained cognizant of related work done elsewhere, and has

taken care to prevent duplication of effort. For the sake of completeness these activities are mentioned here, although NAG-8-758 only supported these efforts through the indirect means of liason and mutual discussions carried out by John Nousek.

HEASARC Provided Archival Data WORM optical disk copy of entire A-2 MED/HED data set in raw form.

Spectral data files and spectral fit parameters for every MED/HED pointing data set. [The formulation of these data has been specially chosen to make MED/HED results in a format compatible with, and accessible by the EXOSAT database system in use at Goddard and ESTEC.]

Descriptions of the non-standard 'Radical RAM' telemetry formats used during the HEAO-1 mission.

The HEASARC archival work carried out at Goddard after being planned during joint coordination meetings between HEASARC personnel and Penn State, over the period 1991-1992.

In addition to the creation of SARC's the Astrophysics Data System Study also called for the creation of a 'Master Directory' for location and access in uniform way to all of NASA Astrophysical data holdings. John Nousek served as Co-Chair of the Working Group commissioned to develop this directory. The result of that development was the current Astrophysics Data System (ADS), which includes data from currently seven and shortly 10 NASA data nodes, and which went to operational release in July, 1991.

In separate funding provided by the ADS project the HEAO-1 catalogs listed above were reformatted by Penn State staff for inclusion in SQL databases for access through the ADS system. Although initial database creation costs were assumed by the ADS project as a pilot experiment, long term maintenance costs are expected to be borne by the projects or discipline analysis moneys.

Finally, the work completed here will be supported for later improvement and support through the transition to the HEASARC control for the next three years by NASA Contract NAS5-32074, starting in November, 1992, through November, 1995.

HEAO-1 Archive Data Package

User's Manual and Reference Guide

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Version v1.0

February 26, 1993

The HEAO-1 satellite carried out pioneering studies of the X-ray sky over the energy range 0.1 keV to 10 MeV between launch in August, 1977, and its demise in January, 1979. Nearly total sky coverage and large collecting area instruments make the accumulated HEAO-1 data an archival resource of lasting value.

This manual describes the data sets collected, reformatted into modernly accessible forms and archived in an effort at Penn State University lead by Dr. John A. Nousek over the period 1989-1992.

Contents

1 Introduction

When it was launched (1977) the first High Energy Astrophysical Observatory satellite (HEAO-1) tremendously expanded the available amount of X-ray data about the astronomical universe. With a suite of detectors that spanned the energy range from 100 eV to 10 MeV, and scanning the entire sky to far greater sensitivity levels than possible before, HEAO-1 literally opened a new window onto the heavens.

During their period of operation the instruments conducted a unique, broad spectrum survey of the entire sky. ROSAT (0.1-2 keV) and GRO (>100 keV) have surpassed the HEAO-1 sensitivity, but not over the same width of bandpass. Even where the HEAO-1 sensitivity limits are surpassed, the data remain an invaluable archive for monitoring temporal changes in the brightness and spectrum of sources.

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The original data processing and analysis for HEAO-1 was based on the pure Principal Investigator (PI) model in use when the mission was carried out. Data were returned to the PI team, who had sole responsibility for the use and analysis of that data. The PI team then planned software and analysis procedures which were suitable for the limited period of time after data receipt for which the mission funded data analysis (typically 3-5 years). Outside investigators were able to work on data by special arrangement with the PI team, and were expected to learn the PI specific software or relied on PI team members to perform the analysis (typically by forming collaborations leading to publications).

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In 1988 a working group developed a comprehensive assessment of data holdings and analysis management entitled the 'NASA Astrophysics Data System Study'. It recognized this problem and recommended the establishment of Science Archive Research Centers. At such centers the overhead of maintaining expertise and supporting archival databases could be shared amongst several missions, allowing a yet more extended useful life.

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In 1989 John Nousek of Penn State University received funding to perform the necessary migrations of data and software from the PI teams into a framework consistent with modern archival media, and modern software environments. As the total funding over the entire three year period totalled only $200,000, and five different software archives needed to be created and saved, it became imperative to adopt a 'triage' approach to saving data. Work was done immediately upon the most important data sets, and the transfer of data from perishable deteriorating magnetic tapes. Only conceptual planning was done for the lower priority data. Certain low level data products with poor

or non-existant documentation were written off as hopeless.

In 1992 an additional three year proposal was approved through the Astrophysics Data Program (ADP) to continue support for these data products, to extend the data archived and to maintain and support accessibility to these data through the Astrophysics Data System (ADS). Data sets produced through this supplementary program are not described in this document, although it is intended that such additional data will be provided in compatible forms to act as a supplement to this archival package.

2 Structure of the Archive

The data sets are grouped according to the experimental team which collected them. Although technically there were four experiments defined in the nomenclature of the HEAO-1 program, one of those was sub-divided into two functionally separate organizations. Hence the data sets are divided into five categories. A very brief functional sketch of the operational division is provided here. Each experiment archive also contains a narrative description within the archive.

[Note: the experiments are all named HEAO A-x, rather than HEAO-1 because prior to launch the then planned satellite was named HEAO-A. After launch the satellite became HEAO-1, but the experiments retained the A-x nomenclature.]

2.1 The Experiments

HEAO A-1 This experiment consisted of seven extremely large area thin window collimated proportional counters, spanning the energy range from 0.25 to 25 keV. The experiment team was located at the Naval Research Laboratory in Washington, DC, and was initially headed by Dr. Herbert Friedman, and later by Dr. Kent Wood.

HEAO A-2 LED The A-2 experiment consisted of a large collaborating set of institutions. Operationally the two thin window gas flow proportional counters (LED), covering the energy range from 0.1 to 2.8 keV, were analyzed by a consortium of scientists from the California Institute of Technology, the University of California, Berkeley and the Jet Propulsion Laboratory under the direction of Dr. Gordon Garmire. Shortly following the operational end of the HEAO-1 mission Dr. Garmire moved to the Pennsylvania State University and continued analysis there.

HEAO A-2 MED & HED The other four detectors of the A-2 experiment were sealed gas proportional counters. Consisting of one detector designed for a medium energy response (MED) [covering 1.2 to 20 keV], and three with a high energy design (HED) [covering 2.5 to 60 keV], these detectors were built and operated by a team from the Goddard Space Flight Center under the leadership of Dr. Elihu Boldt.

HEAO A-3 The A-3 experiment consisted of a scanning modulation collimator proportional counter. This device produced highly accurate positions of X-ray sources down to 1 μJy over the 1-15 keV energy range, but required either a model of the position and intensity of all sources within its 4x4 degree field of view or allowed a multiplicity of small disjoint error boxes. Originally this experiment was built under the leadership of Dr. Herbert Gursky at American

Science & Engineering (AS&E) and Dr. Hale Bradt of the Massachusetts Institute of Technology, and most recently has been lead by Dr. Dan Schwartz of the Smithsonian Astrophysical Observatory.

HEAO A-4 The A-4 experiment consisted of a Hard X-ray and Low Energy Gamma-Ray Experiments spanning the 10 keV to 10 MeV energy range using scintillation spectrometers and collimators. Dr. Larry Petersen of the University of California, San Diego (UCSD), and Dr. Walter Lewin of the Massachusetts Institute of Technology, were the original team leaders. Most recently Dr. Duane Gruber of UCSD has lead A-4 analysis activity.

The following listing describes the available datasets, mostly derived as part of the Penn State archival process, but also resulting from archival activity at the Goddard Space Flight Center and the Astrophysics Data System. In particular the High Energy Science Archival Research Center at GSFC, under the leadership of Dr. Nick White, contributed vitally to the creation of this archive. It is planned that the HEASARC will form the long term repository for this data (and in conjunction with the National Space Science Data Center) will assure its availability as long as scientific interest in the data continue.

A-1 Experiment Machine readable version of the A-1 source catalog (Wood *et al.*).

Machine readable documentation for the A-1 source catalog.

Single day scan maps of the sky intensity seen by A-1.

Narrative description of the A-1 experiment.

A-2 LED Experiment Machine readable version of the A-2 LED source catalog (Nugent *et al.*).

Machine readable documentation for the A-2 LED source catalog.

All sky maps of the sky intensity seen by A-2 LED, in both Aitoff projections and as intensity vs. scan angle and Day number.

Spectral data files and spectral fit parameters from every LED pointing during the entire mission. [The formulation of these data has been specially chosen to make LED results in a format compatible with, and accessible by the EXOSAT database system in use at Goddard and ESTEC.]

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WORM optical disk copy of entire A-2 LED data set in raw form.

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Machine readable documentation for the A-3 catalog.

Narrative description of the A-3 experiment.

WORM optical disk copy of entire A-3 data set in raw form.

A-4 Experiment Machine readable version of the A-4 source catalog (Gruber, private communication).

Machine readable documentation for the A-4 source catalog.

All sky maps of the sky intensity seen by A-4, in both Aitoff projections and as intensity vs. scan angle and Day number.

Narrative description of the A-4 experiment.

Bibliography of the papers written using the A-4 experiment.

Archiving Documentation and Software Documentation describing the HEAO-1 archive, including the data content, directory structure, sources and other pertinent information.

Software and documentation allowing the projection of scan angle vs. Day number onto local tangent plane images or global Aitoff images.

INGRESS SQL format data table forms of the catalogs listed above, with four forms of documentation files for each catalog (general description, list of fields, database template, and scientific examples) [funded by ADS, see below]

HEASARC Provided Archival Data WORM optical disk copy of entire A-2 MED/HED data set in raw form.

Spectral data files and spectral fit parameters for every MED/HED pointing data set. [The formulation of these data has been specially chosen to make MED/HED results in a format compatible with, and accessible by the EXOSAT database system in use at Goddard and ESTEC.]

Descriptions of the non-standard 'Radical RAM' telemetry formats used during the HEAO-1 mission.

3 Contents of the Archive

All the heao A-1, A-2 Low Energy Detector (LED), A-2 Med/High Energy Detector (MED/HED), A-3 and A-4 experiments are stored in one DAT tape with the exception of the A-3 sky maps which are stored on three separate DAT tapes and are only distributed if specifically requested.

This file (directory name: /heao_catalog) contains various information regarding the five HEAO experiment source catalogs. In order to keep the data in an organized fashion several sub-directories were created for each group of related data. These sub-directories are: ads, bibliography, data, ingres and text. The content of each sub-directory is explained below:

3.1 /heao_catalog/ads

This sub-directory contains the description, template, fields and a sample scientific example of the catalogs as used by the Astrophysics Data System (ADS) software. The following files are in this directory:

3.1.1 a1cat.dsc, a2ledcat.dsc, a2medcat.dsc, a3cat.dsc and a4cat.dsc

These files are in machine readable (ASCII) form, containing a brief description of each catalog A-1, A-2 LED, A-2 MED/HED, A-3 and A-4 experiments respectively. This file also contains the data elements included in the Ingres data base file along with an example for each of the elements.

3.1.2 a1cat.fld, a2ledcal.fld, a2medcat.fld, a3cat.fld and a4cat.fld

These files are in machine readable (ASCII) form and contain a list of data elements along with an example for each of the data items. The above file names correspond to the A-1, A-2 LED, A-2 MED/HED, A-3 and A-4 experiments respectively.

3.1.3 a1cat.tpl, a2ledcat.tpl, a2medcat.tpl, a3cat.tpl and a4cat.tpl

These files are in machine readable (ASCII) form, containing the template for the Ingres/SQL data base files. File names correspond to the A-1, A-2 LED, A-2 MED/HED, A-3 and A-4 experiments respectively.

3.1.4 a1cat.xmp, a2ledcat.xmp, a2medcat.xmp, a3cat.xmp and a4cat.xmp

These files are in machine readable (ASCII) form, containing a sample QUERY example for each of the data base files. File names correspond to the A-1, A-2 LED, A-2 MED/HED, A-3 and A-4 experiments respectively.

3.2 /heao_catalog/bibliography

This sub-directory contains the list of available references for each of the five HEAO A-1, A-2 LED, A-2 MED/HED, A-3 and A-4 experiments. File names are: A1-publication, A2led-publication, A2med-publication, A3-publication and A4-publication.

3.3 /heao_catalog/data

The following files are stored in this sub-directory:

3.3.1 A1-catalog.dat

An ASCII (Machine readable) version of A-1 source catalog

3.3.2 A1-catalog.f

This is a FORTRAN program which reads the A1-catalog.dat file and gets rid of the headings and assigns a record number to each catalog entry. The output of this file was used to create an Ingres data base file. Input file is 132 characters long and output file is 136 characters since record numbers are added to the file. For output file format and sample scientific examples, refer to the /ads sub-directory.

3.3.3 A2led-catalog.dat

An ASCII (Machine readable) version of A-2 Low Energy Detector source catalog.

3.3.4 A2led-catalog.f

This is a FORTRAN program which reads the A2led-catalog.dat file and gets rid of the headings and assigns a record number to each catalog entry. The output of this file was used to create an Ingres data base file. Input file consists of 803 catalog entry with no carriage return at the end of each record. This program reads the entire file and writes out the records with carriage return at the end of each entry. Record numbers are also added to each record making the output file 148 characters long. For output file format and sample scientific examples, refer to the /ads sub-directory.

3.3.5 A2med-catalog.dat

An ASCII (Machine readable) version of A-2 Med/High Energy Detector source catalog.

3.3.6 A2med-catalog.f

This is a FORTRAN program which reads the A1-catalog.dat file and gets rid of the headings and assigns a record number to each catalog entry. The output of this file is used to create an Ingres data base file. For output file format and sample scientific examples, refer to the /ads sub-directory.

3.3.7 A3-catalog.dat

An ASCII (Machine readable) version of A-3 source catalog

3.3.8 A3-catalog.txt

Not available at this time. (A completely revised, thorough reprocessing of tha A-3 data has recently been completed by the A-3 team, under the leadership of Dr. Ron Remillard. A machine readable form of the catalog has been promised but not yet delivered.)

3.3.9 A3-catalog.f

This is a FORTRAN program which reads the A3-catalog.dat file and gets rid of the headings and assigns a record number to each catalog entry. The output of this file is used to create an Ingres data base file. The input file is variable record length, the output file is a fixed record length of 80 characters per record. For output file format and sample scientific examples, refer to the /ads sub-directory.

3.3.10 A4-catalog.dat

An ASCII (Machine readable) version of A-4 source catalog

3.3.11 A4-catalog.f

This is a FORTRAN program which reads the A4-catalog.dat file and gets rid of the headings and assigns a record number to each catalog entry. The output of this file is used to create an Ingres data base file. The output file is 143 characters long. For output file format and sample scientific examples, refer to the /ads sub-directory.

3.4 /heao_catalog/ingres

The "ADS" sub-directory contains the description, field, template and example files describing the HEAO data. This sub-directory contains the HEAO data in Ingres Unloaddb ASCII format. To load the data into Ingres, edit the "reload.ing" for pathnames and usernames, and them type "sh reload.ing".

3.5 /heao_catalog/text

This sub-directory contains a machine readable documentation for each of the source catalogs. The following files are in this directory:

3.5.1 A1-catalog.txt

An ASCII (Machine readable) documentation of the A-1 source catalog. This file was created by scanning the article entitled "THE HEAO A-1 X-RAY SOURCE CATALOG" in The Astrophysical Journal Supplement Series, 56:507-649 1984 December. Some of the tables and Figures are eliminated from the text. For further information the user may need to refer to the original article.

3.5.2 A2led-catalog.txt

An ASCII (Machine readable) documentation of the A-2 source catalog. This file was created by scanning the article entitled "THE HEAO A-2 SOFT X-RAY SOURCE CATALOG" in The Astrophysical Journal Supplement Series, 51:1-28 January 1983. Some of the tables and Figures are eliminated from the text. For further information the user may need to refer to the original article.

3.5.3 A2med-catalog.txt

An ASCII (Machine readable) documentation of the A-2 MED/HED source catalog. This file was created by scanning the article entitled "A COMPLETE X-RAY SAMPLE OF THE HIGH-LATITUDE ($|b|$ >20 degree) SKY FROM HEAO 1 A-2" The Astrophysical Journal Supplement Series, 253:485-503 1982 February. Some of the tables and figures are eliminated from the text. For further information the user may need to refer to the original article.

3.5.4 A3-catalog.txt

Not available at this time

3.5.5 A4-catalog.txt

An ASCII (Machine readable) documentation of the A-4 source catalog. This file was created by scanning the article entitled "THE HEAO 1 A-4 CATALOG OF HIGH ENERGY X-RAY SOURCES" in The Astrophysical Journal Supplement Series, 54:581-617 1984 April. Some of the tables and Figures are eliminated from the text. For further information the user may need to refer to the original article. enddescription

4 Acknowledgements

We gratefully acknowledge the help and valuable scientific contributions of the HEAO-1 team members who provided data or other information to make this project possible. The following individuals are particularly worthy of thanks, K. Wood and P. Hertz, NRL; R. Fink, R. Kraft, A. Wilcox, PSU; K. Jahoda, F. Marshall, E. Boldt, J. Swank, GSFC; D. Schwartz, SAO; R. Remillard, MIT; D. Gruber, UCSD; and N. White, W. Pence, and W. Snyder, HEASARC.

This project was made possible by the long term vision of the Science Operations Branch under Dr. Guenter Riegler, and in preceeding years by the support of the High Energy Astrophysics Branch under Drs. Al Opp, Alan Bunner and Lou Kaluzienski. This project was supported by NASA Grant NAG 8-758.