I. DATA IN SPACE ASTRONOMY

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DATA AND DATA RETRIEVAL IN SPACE ASTRONOMY

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ABSTRACT

To illustrate the range of storage and retrieval facilities and data products that are involved in space astronomy, the present situation on data from some instruments on the following missions is presented: Small Astronomy Satellite-B, Orbiting Astronomical Observatory 3, High Energy Astrophysics Observatory 2, International Ultraviolet Explorer, Viking Orbiter, and Solar Maximum Mission. In addition the Coordinated Data Analysis Workshops conducted at the National Space Science Data Center are outlined to demonstrate the usefulness of building a problem-oriented on-line data base from instruments flown on a number of spacecraft and operating from ground-based facilities.

1. INTRODUCTION

With the advent of artificial satellites carrying instruments above the Earth's atmosphere, the spectral range of observation available to astronomers was increased enormously. The major thrusts have been in the ultraviolet (UV), extreme UV (EUV), X-ray, and γ-ray regions. Not only have a variety of instruments been flown which are sensitive in this range of the electromagnetic spectrum, but there are a variety of ways in which such data have been processed and archived for use by astronomers for further study. Several of these ways will be outlined in this introduction and more details for a specific example of each will be given. This should provide the reader with a reasonable understanding of both the data and their accessibility, or retrieval, in space astronomy at the present time.

The first mode used in conducting a flight astronomical investigation was the Principal Investigator (PI) mode, where the PI was responsible for the instrument design, construction and

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calibration as well as the extensive data processing and analysis that follows the receipt of the telemetered data from the satellite. The example selected to detail this approach is the second Small Astronomy Satellite (SAS-B) launched in November 1972, which explored for seven months the spectral range between 30 and 200 MeV. Another approach has been the sharing of available observing time by astronomers as Guest Investigators (GI) on an instrument, which was handled in all respects by a PI. The GIs were chosen from a set of proposed tasks by a peer review process which prioritized these proposals on their scientific merit. An example of this mode of operation is given by the UV Telescope covering the 95-320 nm range on the third Orbiting Astronomical Observatory (OAO 3), which operated from August 21, 1972, until shut down on February 15, 1981.

A third approach has been used on the second High Energy Astrophysics Observatory (HEAO-2), where an orbiting X-ray telescope facility was constructed under the direction of a PI and a number of focal plane instruments were each supplied by experts, who formed members of a consortium. A Guest Observer (GO) program has also been conducted by the PI so that observations were specified by the PI, the three consortium members, or the GOs. The spectral range from 0.2-4 keV was covered by this facility. A more classical approach for astronomers is used in the case of the International Ultraviolet Explorer (IUE). A facility employing a Ritchey-Chrétien telescope performing in the region from 120-325 nm is available only to GIs, who make proposals for specific observations and are selected in a peer review process. One third of the operating time is scheduled by the UK and ESA experimenters during which the spacecraft is handled by the ESA VILSPA control center in Villafranca, Spain. The other 16 hours are controlled by Goddard Space Flight Center (GSFC) for US and non-European investigators.

A fifth variant was exemplified by the Viking Orbiter Imaging Investigation. In this case, a team of scientists specified the characteristics of twin TV cameras operating in the visible spectrum and the photographic products which would be provided to them. This team consisted of 14 scientists from nine institutions. Although there was a proprietary data rights period for this team, other scientists were also supported to carry out research utilizing the photographic data products.

The last approach that will be detailed here is that utilized by the Solar Maximum Mission (SSM). In this mission, each of seven instruments was contributed by a PI-led team (in one case there were three Co-PIs involved). A very tight command and control loop with five of the instruments, which has required separate computer systems for each operating in near real-time, has been conducted. The detailed analysis of the data will be carried out in a coordinated fashion on a single computer, which is called the Data Analysis Center (DAC). The

SMM solar pointing platform is instrumented to make observations from the IR through the γ-ray region.

For these specific space astronomy projects, the details of the measurements, the data products available, and the sources for such products will be given. For most of the missions, data are deposited in the National Space Science Data Center (NSSDC) at GSFC. Any data deposited at NSSDC are available to scientists outside the United States through the co-located World Data Center A for Rockets and Satellites (WDC-A-R&S). For brevity in what follows, the acronym NSSDC will be used to represent NSSDC/WDC-A-R&S.

2. DATA FROM THE SAS-B GAMMA-RAY TELESCOPE

The instrument consisted of two spark-chamber assemblies, four plastic scintillation counters, four Cerenkov counters, and an anti-coincidence scintillation counter dome assembled to form a telescope. The spark-chamber assembly consisted of 16 wire modules with thin tungsten plates interleaved with the planes of wires to serve as electron-positron pair converters. The measurement of the resulting charged pairs allowed the determination of the direction and energy of the incident γ-ray. The four scintillation counters formed a plane between the two spark-chamber assemblies. The four directional Cerenkov counters, placed below the assemblies, constituted four independent counter coincidence systems. The single-piece plastic scintillator dome surrounded the whole assembly, except at the bottom, to discriminate against viewing charged particles passing through the chamber. The angular resolution of the telescope was about 2.5° although it varied with energy and angle. The dome scintillator was sensitive to γ-ray bursts with energies in the 150-600 keV range.

The processing and analysis of these data were carried out under the direction of Dr. Carl E. Fichtel, GSFC. A number of Co-Investigators (CoIs) were involved with these activities. Approximately three years after launch the following data products were submitted to NSSDC for archiving. There is a microfilm data set containing pictures of the electron pair spark-chamber tracks for over 3 million γ-rays. In connection with γ-ray burst activity there are tables, plots and magnetic tapes containing the dome anti-coincidence counter rate as a function of time. As a final product, there are hard copy tables of γ-rays observed in the energy band 35-100 MeV and > 100 MeV in each of 144 elements of equal solid angle with a 2.5° latitude bin. The exposure factor for each element is also provided. During the lifetime of the experiment from November 15, 1972, to June 8, 1973, approximately 55 percent of the celestial sphere, including the galactic plane was surveyed. Any other data still existing from this experiment are held by the PI.

3. DATA FROM THE OAO 3 UV TELESCOPE

The instrument consisted of a 0.8-m diameter Cassegrain telescope with a 16-m focal length (f/20). A Paschen-Runge spectrometer with two pairs of movable photomultiplier tubes (PM) provided both high and low resolution spectra in ranges 95-145 nm and 160-320 nm. The high resolution was 5 and 20 pm; the low resolution was 10 and 40 pm, respectively. The high resolution made it impractical to obtain complete spectral coverage of every object observed. Stabilization of the whole device was about 0.1" in pitch and yaw. Professor L. Spitzer of Princeton University was the PI for this investigation. The GIs accounted for about 20 percent of the observations that were made. The amount of processing accomplished by the PI for the GI was small. The raw data consisted of encoder positions and PM counts. The processing consisted of converting the encoder positions into temperature uncorrected wavelength values in the star's reference frame and the PM counts into source plus background photons. In addition, a background parameter was provided. This was the form of data provided to the GIs. The temperature correction and the removal of background for the short wavelength PM tubes were trivial. However background corrections for the long wavelength were rather complex. All analysis routines were supplied by the individual GIs at their own facility.

The PI was responsible for all requests for data until the completion of the program. The data began being archived in the form provided to the GIs at NSSDC several years ago. A copy of the algorithms that are necessary to perform the final reductions will soon be provided. In addition, an observing catalog with extensive cross references will be provided so that all the observations of a single source can be located and reduced to final form. For a few objects complete low resolution spectral scans were made. NSSDC has on magnetic tape a spectral atlas for Tau Scorpii and for Iota Herculis.

4. DATA FROM HEAO 2

The Einstein Observatory, HEAO 2, had a large grazing incidence X-ray telescope with a 1° x 1° field-of-view (FOV). There were four interchangeable focal plane detector systems. The first was a channel plate imaging array with a pixel size of about 2" sensitive in the range 0.2-4.0 keV. This system and the telescope were the responsibility of Professor R. Giacconi and Dr. H. D. Tananbaum of the Harvard College Observatory/Smithsonian Astrophysical Observatory Center for Astrophysics (CFA). A bent-crystal Bragg spectrometer employing six different crystals was provided by Prof. R. Novick of Columbia University to measure X-ray line emission from 0.18 - 3 keV. The resolution, $\gamma/\Delta\gamma$, varied from the range of 50-100 up to 200-1000 depending on the crystal. A thin-window position sensitive proportional counter was used as the detector. An imaging proportional counter with a 1" resolution was used in the range 0.1 to 4 keV to study weak sources, to determine the angular structure of extended sources, and to locate objects with poorly known positions. This device was supplied by Prof. G. W. Clark of MIT. A cooled solid-state spectrometer was supplied by Dr. S. S. Holt of GSFC. A lithium-drifted detector was operated at 120° K and spectral measurements between 0.5 and 4 keV were done with a resolution of 120-150 eV full-width at half maximum.

Prof. Giacconi was the PI for all detector systems and all observations were processed at CFA to correct for attitude, merge data, search for the existence of sources, determine source location and record spectral strengths. The algorithms to process the various detection systems were supplied by consortium members.

Observation time was divided among the PI, consortium members, and GOs. The GO observing time was 20 percent during the first 18 months of the program and built up to about 35 percent by the end of mission life. The spacecraft was launched November 13, 1978 and operated until April 25, 1981. Production tapes were copied and sent to MIT, GSFC, and Columbia for the consortium observations. Production files are maintained on magnetic tape; summary files are printed and microfiched for storage. About three months after each observation was made, all data had been processed. At that time a GO would go to CFA to analyze the data on the Einstein computer system. Analysis programs to handle spectra and time history as well as smoothing and deconvolution routines, were available for use by the GOs.

The GO program will continue for several years with the PI handling the data. An observing catalog (OCA) which gives the scheduled target name, coordinates, focal plane instrument, and observing interval through February 28, 1981, has been deposited with NSSDC. This OCA will be updated to include the whole mission lifetime by November 1981. A year later the OCA will be updated to include actual durations and dates, as well as an estimate of the time during which good data were accumulated for each target. At that time a preliminary catalog of detected sources will be submitted. Finally, a source catalog and spectral information for all observations will be deposited in NSSDC by September 1984.

5. DATA FROM IUE

The IUE telescope has a 45-cm beryllium primary and a 9-cm silica secondary mirror. The instrument is 1.30 m long, has a 6.75-m focal length (f/15) and a 16'-FOV. There are two Echelle spectrographs that use SEC Vidicon cameras. Each spectrograph has a high resolution mode of 20 pm and a low resolution mode of 0.6 nm. One covers the range

113.4-208.5 nm in low and 119.2-192.4 nm in high resolution. The other covers the range 180-325.5 nm and 189.3-303.1 nm in low and high resolution, respectively. A circular entrance aperture of 3" is always open and, additionally, a 10" x 20" slit can be used.

The GOs chosen by NASA come to the IUE facility at GSFC when their observations are being made so they can determine the actual exposure times needed on each source by examining the data in near real-time. All observations are processed by the project (US or ESA) to produce geometrically and photometrically corrected spectra on tape, as well as to produce a photographic output that displays the raw spectrum and the processed spectrum in image format. This is known as the photowrite. A line plot of the observed spectrum is also provided to the GO. Any further processing or analysis is done by the GO at facilities to which he has access. The same procedure is used at VILSPA for the European GOs.

Approximately six months after the standard output products have been given to the GO, data on magnetic tape are available at three data centers: WDC-C-R&S in the United Kingdom, VILSPA, and NSSDC. Data are also available from NSSDC on a proprietary basis via special request forms signed by the GO, who thus releases his data to a requesting colleague prior to the standard release date. For observations made from VILSPA there are no photowrites archived. Photowrites of observations made from GSFC are available from NSSDC. IUE was launched January 27, 1978 and is expected to be operational for many more years.

6. DATA FROM THE VIKING ORBITER IMAGING INVESTIGATION

The Viking visual imaging subsystem consisted of twin high-resolution, slow-scan television framing cameras mounted on the scan platform of each orbiter with the optical axes offset by 1.38°. Each camera consisted of a 475-mm focal length telescope, a 37-mm diameter Vidicon, the central section of which was scanned in a raster format of 1056 lines by 1182 pixels, and six color filters to restrict the spectral bandpass of an image to limited portions of the camera's response. The FOV was 1.54° x 1.69° with each pixel subtending 25 radians. The data were processed by the Imaging Processing Lab (IPL) at the Jet Propulsion Lab (JPL) to produce a digital image tape and the supplementary experiment data records (SEDR) which contain 78 parameters associated with each scene. Besides the tapes, the members of the Imaging Science Team headed by Dr. M. H. Carr of the US Geological Survey (USGS) at Flagstaff received processed photographs, both rectilinear and orthographic, of each scene. Additional processing was done by team members and mosaics were made from various photographs. The archive for the image tapes is at JPL. The following photographic products are available from NSSDC:

a. Press Release Photos, Black/White (B/W) & Color 4"x5"
b. B/W Rectilinear Photos 5"x5"
c. B/W Orthographic Photos 5"x5"
d. B/W Mosaics
e. Indexes on microfilm & microfiche
f. SEDRs

All photographic products can be viewed at NASA Regional Planetary Image Facilities (PIF) located at: USGS in Flagstaff, AZ; U. of Arizona in Tucson, AZ; JPL in Pasadena, CA; Washington U. in St. Louis, MO; Cornell U. in Ithaca, NY; Brown U. in Providence, RI; and the Lunar and Planetary Institute in Houston, TX. In addition, cooperative PIFs located at U. of Rome; Rome Italy and U. of London, London, UK also have the photographic products. The Viking 1 Orbiter began operations around Mars on June 19, 1976, and terminated on August 7, 1980. The Viking 2 Orbiter dates were August 7, 1976, and July 25, 1978, respectively. NASA is in the process of generating 35-mm images from all of the planetary image tapes at JPL, which will then be used to produce video disk masters containing 54K images per side. Copies of these disks will be provided to the NASA Regional and Cooperative RIFs as well as NSSDC.

7. DATA FROM SMM

There are seven separate experiments on SMM. Each will be discussed briefly since the data from at least six are going to be resident at the SMM DAC at GSFC. This is a VAX 11/750 computer facility that is being formed to analyze the data from SMM in a coordinated fashion. There has been and will continue to be a GI program. NSSDC will have access to the DAC and appropriately identified data in the DAC will be available to other scientists through NSSDC. Eventually all SMM data processed to the proper level and documented will be archived at NSSDC.

7.1 Hard X-ray Imaging Spectrometer (HXIS)

This instrument (PI - Prof. C. de Jager, U. of Utrecht) produced two-dimensional images with 8" resolution over an approximately square area of 2' 40" per side and with 32" resolution over an approximately square area of 6' 24" per side. These images were observed in six selectable energy channels between 3.5 and 30 keV with a temporal resolution of 0.5-7s, depending on the mode of operation. By means of a flare flag the experiment alerted all the other SMM instruments when a flare began and indicated the position of the brightest pixel. The instrument consisted of 10 etched grid plates, each divided into 576 sections that formed the collimator and 900 mini-proportional counters that provided the detector and spectral capability. A dual microcomputer system permitted three modes of

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operation with commandable parameters that provided a flexible trade-off between temporal and spatial coverage during different phases of a solar flare.

7.2 Soft X-ray Polychromator (XRP)

This instrument (Co-PIs: Dr. L. W. Acton, Lockheed Palo Alto Lab; Dr. J. L. Culhane, Mullard Space Science Lab; Dr. A. H. Gabriel, Appleton Lab) consisted of two Bragg crystal spectrometers. A bent-crystal spectrometer using eight crystals and position-sensitive proportional counters covered seven bands from 0.177-195 nm for Fe lines and 0.317-0.323 nm for the CA XIX line with a 6' x 6' FOV. A flat-crystal spectrometer using seven crystals and proportional counters was capable of scanning the range 0.14-2.24 nm and rastering in 5" steps over a 7' x 7'-FOV with 14" resolution. A microprocessor controlled trade-offs between temporal and spatial resolution with a temporal limit of 64 ms.

7.3 UV Spectrometer and Polarimeter (UVSP)

This instrument (PI - Dr. E. A. Tandberg-Hanssen, Marshall Space Flight Center) consisted of a Gregorian telescope, an Ebert grating spectrometer and a polarimeter that used four CsI PMs and one CsTe PM. The telescope had a 1.8-m focal length with a 66.4-cm^2 aperture and a FOV of 256" x 256". Entrance slits of 1" x 1", 3" x 3", 10" x 10", 30" x 30", 1" x 10", 4" x 4", 15" x 286", and 1" x 180" were available. Rastering over any of the FOV in 1" x 1" steps was possible. The grating was 3600 lines/mm with a FL of 1 m. The spectral range covered was 115-180 nm in 2^{nd} order and 175-360 nm in 1^{st} with spectral resolutions of 2 pm and 4 pm, respectively. The polarizer consisted of two MgF waveplates with 22.5° rotation steps. A microprocessor made this an extremely versatile instrument that could be programmed into a number of sequential modes that could be altered based on the output of HXIS.

7.4 Hard X-ray Burst Spectrometer (HXRBS)

This instrument (PI - K. J. Frost, GSFC) observed the full solar disk in the range 20-260 keV in 15 differential energy-loss channels with a temporal resolution of 128 ms. It consisted of a disk-shaped CsI (Na) central crystal and a CsI (Na) active collimator element that surrounded the central crystal and provided a 40° conical FOV. A circulating memory was also used to provide 1-ms resolution for fast rising bursts without spectral information. Either a constant time or constant count mode could be selected for use with the memory. Using the latter mode, γ-ray bursts could be detected during spacecraft night.

7.5 Gamma-Ray Spectrometer (GRE)

This instrument (PI - Prof. E. L. Chupp, U. of NH) utilized a set of NaI (Tl) and Cs I (Na) crystals to form three separate devices: (1) an actively shielded multi-crystal γ-ray spectrometer, (2) a high-energy γ-ray detector, and (3) an auxiliary X-ray detector. The spectrometer produced a 476-channel energy-loss spectrum every 16 s over the range 0.3-9 MeV. A 2-s time resolution was available in three windows in the 3.5-6.5 MeV range to study prompt line emission at 4.4 and 6.1 MeV. Photons from 0.3-0.35 MeV were recorded with 64-ms resolution. Events in the 10-100 MeV photon range could be observed along with neutrons > 20 MeV. The auxiliary X-ray detector made measurements in the 10-80 and 25-140 keV range with 1 s resolution.

7.6 Corongraph/Polarimeter (C/P)

This instrument (PI - Dr. L. House, High Altitude Observatory) consisted of a coronograph, a polarimeter, and an SEC Vidicon detector. The FOV ranged from 1.6-6 solar radii (SR) in sectors from 1.5 x 1.5 to 6 x 6 SR with a pixel resolution of 10" and size of 6.4". Seven filters covering the 444.8-641.8-nm range were used. Three polaroids with axes 60° apart were used.

7.7 Active Cavity Radiometer Type IV (ACRIV)

This instrument (PI - R. C. Willson, JPL) used three independent pyroheliometers with conical-cavity detectors. The total solar emission from the EUV to the far IR was measured. Each device had a shutter to block the solar radiation and a reference cavity that permanently viewed a surface at known temperature.

7.8 SMM Data Processing

The five experiments HXIS, XRP, UVSP, HXRBS, and C/P had computers of the PDP 11/34 class at GSFC in a facility called the Experimenters Operation Facility (EOF) to process data within 24 hours to plan the next days' schedule. False color images from all but C/P and HXRBS were produced at the EOF. The GRE and ACRIV data were processed at the PIs' home facilities. In addition, false color images and electron density profiles from C/P were processed at the PI's home computers.

7.9 Status of SMM Operations

The satellite was launched on February 19, 1980. By September 23, 1980, a sequencer on C/P malfunctioned ceasing scientific data collection. By November 23, 1980, the spacecraft could only point within 10° of the sun so all experimenters except HXRBS, GRE and ACRIV ceased taking data. The wider FOV instruments are still acquiring data.

8. COORDINATED DATA ANALYSIS WORKSHOPS (CDAWs)

In viewing the archiving and retrieval of space astronomy data, it should be apparent that the main body of this data base resides mainly on magnetic tapes, microform (film and fiche), and photographic film. Small portions at any given time are resident on disks at computer facilities such as the Einstein computer at CFA and the SMM DAC. In association with the fields and particles experimenters involved in solar-terrestrial research, NSSDC has developed a process called CDAW in which problem-oriented data bases have been constructed from instruments flown on 8-10 satellites and from about 60 ground-based instruments. These coordinated data bases (CDB) contain approximately 600 physical parameters and have been limited to about 150 Megabytes. At scheduled times of 3-4 days duration a CDB has been placed on-line on the NSSDC computer and some 30 scientists from around the world have convened at NSSDC to be interactive with each other and with the CDB. In such workshops, the physical parameters have been manipulated and plotted to the specifications of the workshop participants with a typical daily output of 150 line plots.

Following such CDAWs, outputs have been requested by mail, telex or telephone from the CDB by the CDAW participants. A few participants have exercised a CDB remotely from terminals at their own institution. Portions of one of the four CDBs that have been built to date have been placed on a US-based, commercial computer network that can be accessed from Europe and Japan.

Of interest to astronomers may be a CDB that NSSDC has constructed for possible use to study the solar flare outputs on June 7, 21, and 29, 1980, detected by a variety of instruments. At present there are only a total of 35 parameters from the following five experiments: (1) X-ray monitor from GOES 2, (2) transient γ-ray sources from Pioneer Venus 1, (3) HXRBS from SMM, (4) HXIS from SMM, and (5) UVSP from SMM. Experimenters on ISEE 3 and IMP-J have also expressed interest in contributing to this CDB, known as CDB 5.

It is believed that the process of building CDBs and conducting CDAWs may be useful to astronomers in examining sources or regions from the radio frequency to the γ-ray region of the spectrum. Access to, manipulation of, and outputs from such CDBs can be available to astronomers with present day computer and communications technology.