A Short History of X-ray Astronomy Missions and Data

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The Heroic Age

- Solar X-rays from V-2 rockets: White Sands, 1946-1950.
- Nike Asp rocket AA8.243, Eglin AFB Jun 1960: First AS&E X-ray payload, failed
- Aerobee rocket AB3.352, White Sands Jun 1962: Discovered Sco X-1.
- Apr 1963: NRL group finds Crab
- Dec 1970: Uhuru (SAS 1): hard X-ray point sources
- 1970s: 2-10 keV sky surveys with proportional counters (OSO 7, Ariel 5, HEAO 1)
- 1973: Soft X-ray telescope on Skylab for solar studies
- 1970s: Wisconsin group studies soft X-rays from ISM with rockets

The Einstein era

- Einstein had a soft X-ray telescope
- HRI instrument achieved few arcsecond resolution but with low sensitivity. Microchannel plate detector.
- IPC instrument achieved few arcminute resolution with limited spectral resolution. Proportional counter. Thousands of IPC images.
- FPCS, SSS, OGS spectrometers observed few brightest sources with high spectral resolution - precursor to AXAF gratings.
- First X-ray satellite with GO's
- Pipeline processing system, produced XPR files (event lists) and ran DETECT to make source lists.

The 1980s

- Einstein (1978-81): 0.1-2 keV images, proportional counter spectra (SAO, MIT, GSFC, Columbia)
- EXOSAT (1983-86): 2-10 keV proportional counter spectra (ESA)
- Tenma (1983): 2-10 keV proportional counters (ISAS)
- Granat (1989): 10-100 keV coded mask telescope (IKI, France)

The 1990s

- ROSAT (1990): Like Einstein, but better spatial and spectral resolution. PSPC was proportional counter, HRI was microchannel plate. 0.1-2 keV range. (MPE, SAO)
- ASCA (1993): First CCD instrument, better spectra. Marginal imaging capability with foil mirrors. 2-10 keV range. (ISAS, GSFC)
- RXTE (1995): Proportional counters, 2-10 keV, poor (degree) spatial resolution but good timing and large area. (GSFC)
- SAX (1996): Broad band 0.1-100 keV simultaneous observations. Concentrator optics, proportional counters, Phoswich. (Italy)
- AXAF (1998?): Subarcsecond imaging, CCD and microchannel plate detectors, soft (0.1-2 keV) and hard (2-10 keV) X-ray imaging, high spectral resolution gratings.
- Spektr-RG (1998?): Foil mirrors (2 arcmin), proportional counters; coded mask hard X-ray; JET-X telescope with CCD detector.
- XMM (1999?): Large collecting area, 30 arcsec telescopes, CCDs, gratings.

Instrument	Area (1 keV)	Area (6 keV)	Spatial	Spectral
Uhuru	0	800	1 degree	1
Einstein/IPC	70	0	1 arcmin	2
Rosat/HRI	100	0	5 arcsec	-
Rosat/PSPC	220	0	30 arcsec	5
ASCA/SIS	160	100	10 arcmin	50
XTE/PCA	0	6000	1 degree	5
AXAF/ACIS	650	350	0.5 arcsec	50
AXAF/HETG	60	45	-	1000
SRG/JET-X			20 arcsec	50
SRG/SODART	1500	1000	2 arcmin	3
XMM/EPIC	6000	3000	15 arcsec	50
XMM/RGS	100	0	-	400

Data Analysis

- SAO has most experience in imaging instruments: Einstein, ROSAT, AXAF
- GSFC has most experience in non-imaging instruments: HEAO-1, ASCA, RXTE
- Imaging datasets historically larger, require complicated filtering
- AXAF datasets will be even larger
- XSPEC (GSFC): developed for EXOSAT, used for everything. Spectral analysis only
- FTOOLS (GSFC): developed for ASCA, used for XTE. Best for spectral and timing
- PROS (SAO): developed for ROSAT. Best for image analysis.
- ASCDS (SAO): In development for AXAF. Must support both imaging and spectral analysis.

- Main tasks:
- Telemetry to event list (done in pipeline)
- Determine aspect solution: sky coords of photons
- Event list screening: select good events
- Make image: simple binning
- Exposure map: Apply aspect to detector calibrations
- Automated source detection
- Extract spectrum and background
- Model fitting to spectrum
- Timing analysis

What are the differences between satellite instruments?

- Focussing optics or bare detectors
- Wavelength or energy range - IR, UV, etc. Different technology used for different wavebands.
- Spatial Resolution (how sharp a picture?)
- Spatial Field of View (how large a piece of sky?)
- Spectral Resolution (can it tell photons of different energies apart?)
- Spectral Field of View (bandwidth)
- Sensitivity
- Pointing Accuracy
- Lifetime
- Orbit (hence operating efficiency, background, etc.)
- Scan or Point

What are the differences between satellites?

- Spinning or 3-axis pointing (older satellites spun around a fixed axis, precession let them eventually see different parts of the sky)
- Fixed or movable solar arrays (fixed arrays mean the spacecraft has to point near the plane perpendicular to the solar-satellite vector)
- Equatorial or polar orbit (equatorial allows higher mass, if low enough also less radiation; polar allows sun-synchronous operation).
- Low or high orbit (low orbit has higher radiation, atmospheric drag, and more Earth occultation; high orbit has slower precession and no refurbishment opportunity)
- Propulsion to raise orbit?
- Other consumables (proportional counter gas, attitude control gas, liquid helium coolant)

What are the differences in operation?

- PI mission vs. GO mission

  PI = Principal Investigator. One of the people responsible for building the satellite. Nowadays often referred to as IPIs (Instrument PIs).

  GO = Guest Observer. Someone who just want to use the satellite. (Confusingly. the GO is the PI on his or her own grant, which is different from being a PI on the mission).

  A 'PI mission' is one in which the PIs get all the observing time. A 'GO mission' is one in which the GOs get most of the time. The PIs are guaranteed some fraction of the time (and are GTOs, Guaranteed Time Observers) as a reward for the decades of work invested in building it.

  The first GO missions were IUE and Einstein. Nowadays all big missions are GO missions (ASCA, AXAF, HST) but some smaller ones (COBE, Alexis) are PI missions.

- Sky Survey vs. Observatory

  Some missions scan the whole sky, cataloging every source they can see. Other missions are pointed at specific targets which are already known to be there (because they were discovered in a sky survey).

Science goals of AXAF

- - Community facility like HST, ROSAT; participation by non-X-ray-astronomers encouraged.
- - High resolution spatially resolved X-ray spectroscopy for:
  - Evolution of quasars to high redshift
  - Evolution of clusters of galaxies
  - Structure and physics in low redshift clusters
  - Abundance and plasma conditions versus position in supernova remnants
  - Faint X-ray sources and the background
  - Detailed transmission grating spectroscopy of galactic binary sources.

Who? The AXAF Project:

- Management: NASA Marshall Space Flight Center, Alabama
- Science Center: AXAF Science Center
  - Headquarters at SAO, Cambridge MA and MIT, Cambridge MA
  - Software Beta Test sites at Chicago, Stanford, Hawaii
  - ASC Director: Harvey Tananbaum, SAO
  - User Support Group: Fred Seward, Andrea Prestwich, Eric Schlegel, Nancy Evans
- Mission Support Team: SAO
- Instrument teams:
  - ACIS: MIT/Penn State
  - HRC: SAO
  - HETG: MIT
  - LETG: Utrecht
- Industrial Contractors:
  - Spacecraft: TRW
  - Aspect camera: Ball
  - Upper Stage: Boeing

When?

- Mirror manufacture: Done!
- Instrument assembly and calibration: Now!
- Mirror coating: Completed Feb 1996
- Mirror assembly: Soon!
- Telescope calibration: Jul 1996- Feb 1997
- PROPOSALS: *** Fall 1997 ***
- Launch: Summer 1998
- Lifetime: At least 5 years

What?

- The AXAF-I observatory is a single spacecraft (A companion AXAF-S was cancelled).
- Launch by Space Shuttle with IUS upper stage and GRO derived liquid propulsion system into high orbit
- Movable solar arrays allow wide area of sky to be observed.
- Four nested X-ray mirror pairs, hyperboloid and paraboloid, coated with Iridium
- Two transmission gratings
- Four focal plane detectors

What does a high orbit mean?

- 64 hour orbital period
- - Small part of sky obscured for long periods (few deg region for two years at a time?)
- - Don't observe in radiation belt regions (10 hours of every 64)
- - Long observations possible (up to 54 hours uninterrupted viewing)

Imaging instruments: ACIS-I

The ACIS (AXAF CCD Imaging Spectrometer) has two components: ACIS-I and ACIS-S, with a total of ten 1024 x 1024 X-ray CCDs.

The ACIS-I array has 4 CCDs arranged in a square.

What does a CCD do for you? The first one flown was on ASCA.

- Advantages:
  - High Spectral Resolution in each pixel
  - Broad response (0.2-10 keV)
  - 16 x 16 arcmin FOV
  - Spatial resolution better than 2 arcsec even far off axis
- Disadvantages
  - Radiation degrades spectral resolution over time
  - Lower time resolution than proportional counters, since must read out the chip
  - No very soft X-ray response
  - Gaps between chips

Imaging instruments: HRC-I

The High Resolution Camera (HRC) imaging detector is a microchannel plate, a larger version of the HRI flown on Einstein and Rosat. “Pixels” run from 1 to 16384 - a big dataset!

0.5 arcsec FWHM on axis, degrades to 10 arcsec at 10 arcmin off axis. 30 arcsec FWHM over whole 32 x 32 arcmin field.

- Advantages:
  - Good spatial resolution on axis
  - Soft X-ray response
  - High time resolution
  - Wide area (32 x 32 arcmin)
- Disadvantages:
  - No spectral resolution
  - Lower sensitivity
  - Worse off axis spatial resolution

Transmission Gratings: HETG

The HETG will disperse the X-ray photons which then fall on one of the spectroscopic arrays, usually ACIS-S.

With ACIS-S we have two measures of the photon energy: the CCD pulse height and the dispersion angle. This helps to resolve the grating order confusion.

- Advantages:
  - High spectral resolution
- Disadvantages:
  - No soft X-rays
  - 10 times lower throughput than imagers

Transmission Gratings: LETG

The LETG disperses the X-ray photons onto the HRC-S spectroscopic array.

- Advantages:
  - High spectral resolution at low energies
- Disadvantages:
  - Order separation problems at higher energies.

Data Analysis

The AXAF Science Center will process the data and maintain a database of all the AXAF data. Data will be made available in FITS formats similar to those for ROSAT and ASCA data, so you can do basic analysis of the data with existing packages (IRAF/PROS, FTOOLS/XSELECT/XSPEC, MIDAS/EXSAS). We will also provide specialized analysis tools, which will be needed if you want to recalibrate or if you want to make full use of the information in the datafiles. We hope that this system will build on the existing ones and be nicer to use!

- Programs will work on either FITS or IRAF data formats, transparently; and in conjunction with either FTOOLS or IRAF programs.
- Emphasis on uniform, generic interface to data: spatial, spectral, temporal filtering, binning, manipulations will have unified syntax, which can be extended by user to manipulations on other parameters in data (e.g. phase, housekeeping).
- Emphasis on separating science algorithms from data format details - will provide simple subroutine library for C or Fortran programmers to access data at scientific object model level (as opposed to FITS record/keyword level).
- Emphasis on improved spatial analysis (weakest in current packages). Will collaborate with Keith Arnaud to integrate XSPEC for spectral analysis.

Calibration

The X-ray Calibration Facility in Huntsville, Alabama:

- Let's make sure we can make in-focus pictures!
- Pump down entire mirror/instrument combination in huge vacuum bottle, with quarter-mile evacuated source tube
- Calibrate mirrors with special proportional counter detectors
- Mask off shells and quadrants
- Then calibrate instrument/mirror, instrument/grating combinations
- Tilt mirror to obtain off axis calibrations
- Move instruments to remain on mirror axis
- Dither HRC to avoid burning holes in it
- More than 1 Terabyte of data expected!
- Need to correct for 1-g sag of mirrors, finite distance of source, etc.