Astronomical Data Analysis Software and Systems VI
ASP Conference Series, Vol. 125, 1997
Gareth Hunt and H. E. Payne, eds.

The AXAF Science Center Performance Prediction and Calibration Simulator

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Abstract. We are developing and integrating software to simulate the focal plane detectors, shutters, and gratings for the Advanced X-ray Astrophysical Facility (AXAF). AXAF is one of four observatories in the NASA "Great Observatory" series, scheduled for launch in 1998. AXAF will offer unprecedented spatial and spectral resolution in the X-ray band ranging from 0.1–10 keV. The path of X-ray photons is simulated from the exit of the telescope mirrors to the focal plane. Each major functional element of the simulation is represented by an independent module. Module execution and inter-module communication is accomplished within a pipeline architecture. The software is written in C/UNIX and utilizes a number of existing astronomical software libraries. Detailed models are being developed for the two focal plane instruments. These instruments are ACIS, which is a CCD camera, and HRC, which is a microchannel plate detector. Realistic detector output files are generated in a variety of formats. The simulations are currently being used for planning calibration activities, on-orbit performance prediction and for testing the analysis and telemetry software.

1. Introduction

We are developing computer models to simulate the focal plane detectors of the Advanced X-ray Astrophysical Facility (AXAF). The models, being developed as part of the AXAF Science Center, are being used to aid in calibration planning and to characterize the performance of the AXAF observatory. Scripts have been developed to configure and run the simulations automatically from a test database. Depending on the output mode selected, the results can be viewed directly, sent through telemetry processing, or fed into higher-level analysis pipelines in the Data System.

Much of our work has been focused on developing high-fidelity simulations of the two main Scientific Instruments located in the focal plane of the telescope. These are the AXAF CCD Imaging Spectrometer (ACIS) and the High Resolution Camera (HRC). In addition to these, we have integrated gratings modules and we use output from other simulators which model the sources and telescope mirrors (see Figure 1).

1.1. AXAF CCD Imaging Spectrometer (ACIS)

ACIS is a charge-coupled device optimized for X-ray detection. Its 24μm pixel size offers $^1/_2''$ resolution in the AXAF focal plane. The field of view is $16\times16'$ for

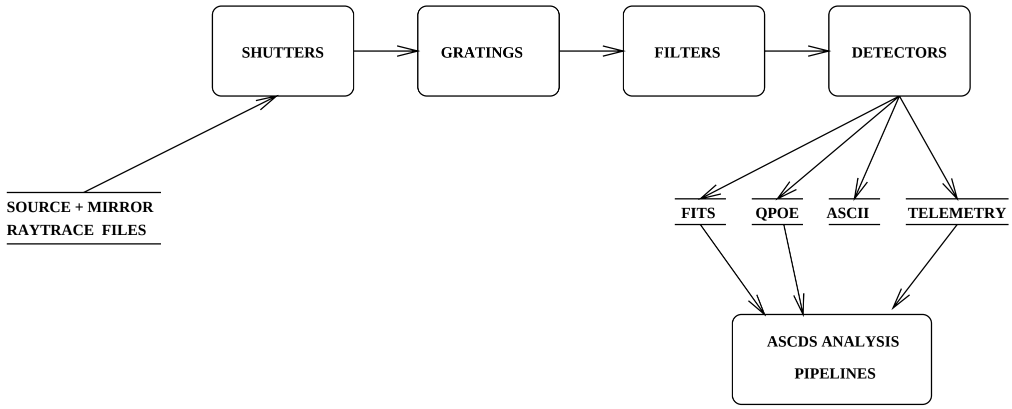

Figure 1. **Simulation Schematic.** The SHUTTERS module simulates 16 separately configurable shutters behind the mirror assembly. The GRATINGS module simulates the High, Medium, and Low Energy Transmission Gratings. The FILTERS module simulates optical blocking filters in front of the detectors. The detectors are ACIS (a charge coupled device) and HRC (a microchannel plate).

the imaging array and $8\times48'$ for the spectroscopic array. The chip is modeled as a multilayer structure. The incident X-ray photons create a charge cloud whose position and size are determined by the silicon absorption depth, the photon energy, the photon position and the dopant concentration. The charge cloud then drifts to the surface of the chip under the influence of a layer dependent electric field, which we model using a Monte Carlo method. At the surface, the charge is mapped onto a 3×3 pixel array. The functional dependence for the number of electrons (n_e) created by an incident X-ray of energy E_x is given by $n_e \sim n_x(E_x/\Delta E)$. Here, n_x is a function calculated by the Monte Carlo program and Δ=3.65 eV is the energy required to liberate a charge carrier. Additional features modeled include read noise, charge transfer inefficiency, bias, gain, and layer thicknesses. The algorithms used in the CCD simulation are based on the program XRAYSIM developed by Lumb et al. (1994), which in turn was based on analytical calculations by Janesick (1987, 1988) and Hopkinson (1987).

The simulator can be operated in two modes. The *Event List Mode* outputs the abovementioned 3×3 pixel array to a FITS event list. This mode is designed for high throughput and does not model effects which arise when two photons hit the same location on the chip in a given integration period. The *Full Frame Mode* embeds the 3×3 pixel array in a much larger rectangular array in memory. This mode includes the effects which arise when multiple photons hit the same location in a given integration period. The *Full Frame Mode* has two output formats available. The events can be extracted from the array in memory using the same algorithm used to detect events in real ACIS frames. The extracted events are output to a FITS event list. Alternatively, the full arrays can be written to FITS image files, one for each integration period. These image files are similar to those produced by the physical chips before event extraction. Event detection in the array in memory yields substantial performance gains over detection of the events in the FITS image files.

1.2. High Resolution Camera (HRC)

The HRC is a microchannel plate (MCP) detector that provides a spatial resolution of less than $^1/_2''$. The field of view is $31\times31'$ for the imaging array and $7\times97'$ for the spectroscopic array. Resolving power is limited, with $E/\Delta E \sim 1$. The simulation models the UV Ion Shield (UVIS), the MCP itself, and the wire charge grid. The UVIS is modeled using a generalized filter program that statistically simulates photon absorption by applying a transmission curve to the input photon energy. The MCP surface is modeled as a surface of circular pores with a diameter of 0.0125 mm and spacing of 0.015 mm. A model of quantum efficiency as a function of incident angle is also applied. The wire grid charge resulting from the charge cloud produced by the MCP is modeled by a scaled Lorentz function. Events are passed into a telemetry simulator that models dead time induced by telemetry bandwidth limitations. Output modes are raw telemetry, FITS event list, and QPOE image formats. The HRC simulator has also been adapted to simulate a similar instrument called the High Speed Imager (HSI) which is used for telescope mirror calibration.

1.3. Mirror and Grating Modules

The mirror simulation's raytrace output can be projected directly on to the model detectors, or diffracted by the gratings module before projection on to the model detectors. The dispersed gratings spectrum provides a resolving power of $\mathrm{E}/\Delta\mathrm{E} \sim 10^{2\rightarrow 3}$. The High Energy Transmission Grating is typically used in conjunction with the ACIS detector and the Low Energy Transmission Grating with the HRC.

2. Architecture

The simulator control hierarchy is depicted in Figure 2. The simulators run as a set of UNIX processes, each of which represents a physical component being modeled. These processes are started, monitored, and stopped by the ASCDS Pipeline Controller. The simulators utilize common ASCDS libraries where possible, such as the IRAF parameter interface. Events (photons) are passed from one process in the pipeline to the next with each process performing some necessary action on an event before passing it along. The action may be to alter the event or to decide not to propagate it. The simulators are implemented primarily in C, with some supporting code written in Perl.

3. Conclusions

The software is designed to easily accommodate modifications and enhancements. The modular pipeline approach has facilitated the interchange of modules as we continue to upgrade the fidelity and capabilities of the simulations. In order to further improve flexibility and provide access to data in the simulator pipelines, a C++ Application Program Interface to the simulator data stream is being prototyped.

Acknowledgments. This project is supported by NASA contract NAS8-39073 (ASC). We would like to thank the following individuals for their contributions to the simulations. Terry Gaetz, Diab Jerius, and Dan Nguyen developed

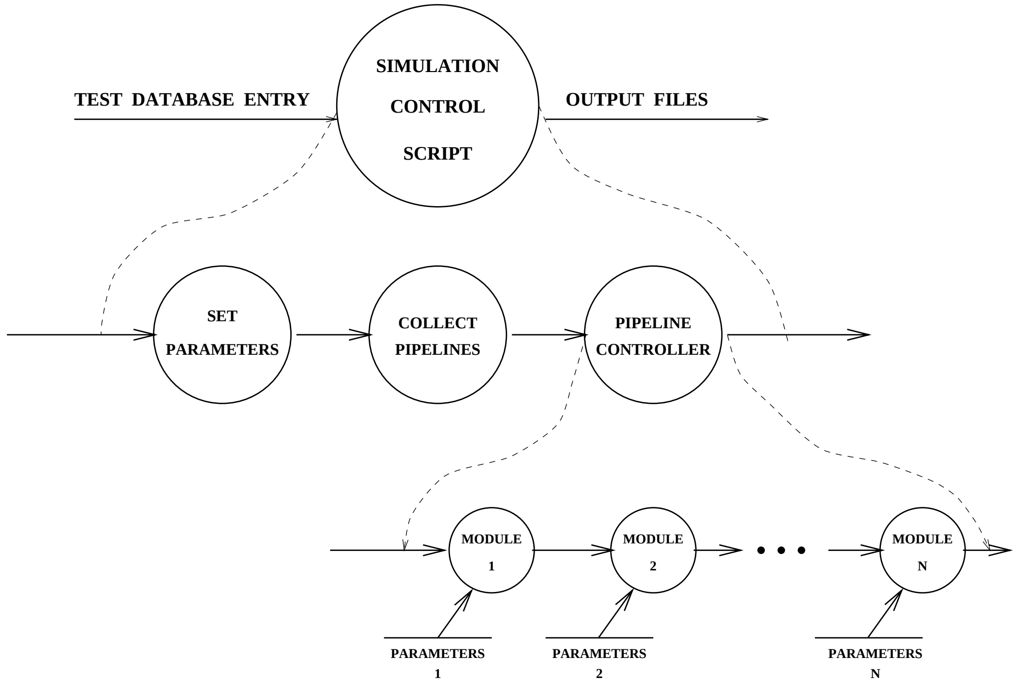

Figure 2. **Simulation Control Hierarchy.** The hierarchy of program control is depicted. Using database entries describing the test to be performed, parameters describing the configuration are set. The ASCDS pipeline controller initiates the raytrace and monitors program execution.

the mirror and source models. John Davis, Dan Nguyen, and Mike Wise developed the gratings model. Diab Jerius developed the HRC pore surface model. Dave Plummer developed the HRC Telemetry dead time simulation. Adam Dobrzycki developed the HRC charge grid algorithm.

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