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Simulated AXAF Observations with MARX

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Abstract. The AXAF Science Center group at MIT has developed an end-to-end simulator of the AXAF satellite called **MARX**. **MARX** includes models of the AXAF mirrors, the low- and high-energy transmission grating assemblies (LETG and HETG), and the HRC and ACIS focal plane detectors. We discuss the role of **MARX** within the ASC Data System and present sample simulated images and spectra for two typical cosmic X-ray sources.

1. Introduction

The AXAF Science Center (ASC) Data Analysis System will include the ability to simulate the detailed response of the AXAF satellite to X-ray sources. These simulations will be used for a variety of purposes including: development of processing algorithms; ground-based and on-orbit performance prediction; testing of the standard processing pipelines; and scientific observation planning and prediction. As part of this modeling effort, the AXAF Science Center group at MIT has developed a modular, portable, stand-alone simulator **MARX** (**M**odel of **A**XAF **R**esponse to **X**-rays). In this paper, we will briefly discuss some of the motivations which have driven **MARX**'s development as well the simulator's current level of functionality. To demonstrate its capabilities, we present simulated AXAF images and spectra for two cosmic sources.

2. Motivations

MARX was originally developed to provide sample AXAF data with an *exactly* known instrument response in order to develop and test spectral extraction and analysis algorithms. It has since developed into an accurate and flexible model of the in-flight capabilities of AXAF and provides a fast and portable alternative to other simulation methods. Here we list some of the uses **MARX** simulations serve within the ASC Data System:

- **Development of data analysis software**
  MARX provides realistic data incorporating a variety of physical effects which characterize AXAF. These data can be used to develop new algorithms, such as event-based spectral extraction of HETG and LETG spectra, or deconvolution of overlapping orders in the case of the LETG. **MARX** simulations provide knowledge of the exact solution for comparison with the reconstructed data.

- **Fitting and Data Analysis**
  As part of the ASC Data System, a fitting application is being designed to allow comparison of models with calibration and flight data (see Doe et al. 1997). This Fit Engine will be capable of driving **MARX** to produce high-quality simulations as part of the fitting process.

- **Calibration**
  Ground calibration of AXAF will utilize detailed predictions to plan the tests and as an aid to the interpretation and digestion of resulting test data. Many of these predictions are being compiled using **MARX**.

- **Flight Observation planning**
  MARX provides a realistic model of the AXAF response to cosmic X-ray sources and can be used for detailed planning of anticipated science programs. One may investigate issues related to sensitivity, spatial resolution, or spectral resolution, for instance. **MARX** will be released to the community as part of the proposal planning software package.

3. Functionality

MARX provides the capability to simulate the various combinations of scientific instruments on-board the AXAF satellite and includes models of the AXAF mirrors, the low- and high-energy transmission grating assemblies (LETG and HETG), and the HRC and ACIS focal plane detectors. For several components of the system, the user may choose between several simulation modes depending on their needs. The mirrors, for example, can be simulated using a simple effective area model or via a full ray-trace if desired. A number of simple source models (extended or point-like) are supported and users may extend the capabilities by incorporating their own models. Sources may have arbitrary spectral energy distributions which are specified via an input ASCII file. **MARX** also provides support for simulations of ground-based calibration tests at XRCF. The HRMA shutter assembly is modeled as well as sources at a finite distance.

4. Implementation

MARX has been coded entirely in C and consists of a single executable. Control of the program is accomplished through a parameter file using the IRAF parameter interface library. The simulator is reasonably compact (requiring only 6 MB for the entire distribution) and fast (3,000 photons/sec on a SPARC 20). It has been successfully compiled under SunOS, Solaris, and Linux. Output from **MARX** can take several forms: a directory of simple binary vectors for each photon property, a FITS photon event list from which images and spectra may be extracted, an SAOSAC DPDE rayfile, or even ASCII files.

5. Sample Simulations

5.1. UX Ari Simulation

UX Ari is a bright RS CVn binary system—a prototypical coronal source. A continuous emission measure model was constructed based on the published

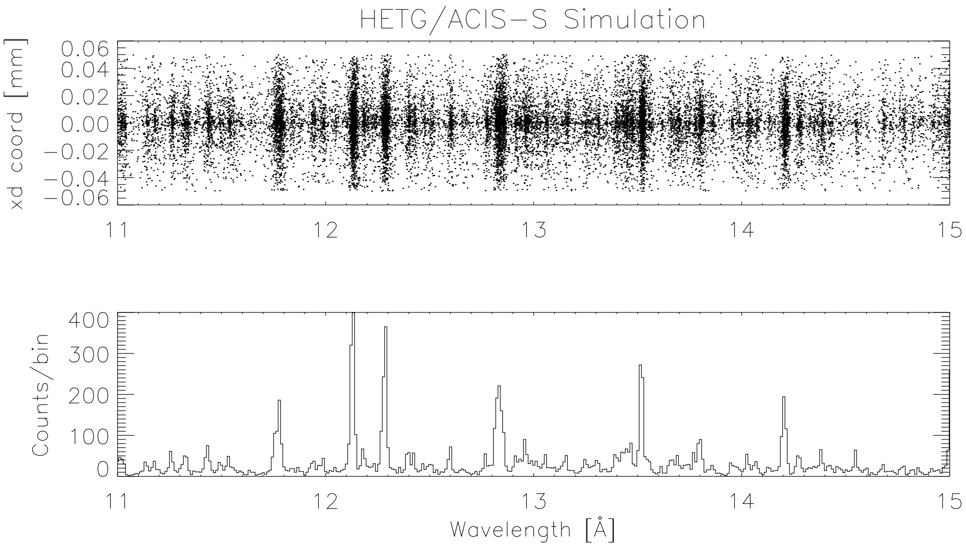

Figure 1. A simulation of a stellar coronal plasma as detected by the HETG with the ACIS-S detector. In the upper panel, an expanded view of the detected photon distribution is shown. Spectral lines show up as dark, vertical bands. The lower panel gives the total counts per pixel for the region of the spectrum shown in the upper panel.

EUVE data (Dupree 1996); the peak emission occurred near 10^7 K. Simulations were run for both the HETG and LETG

with the same input spectrum for an exposure time of approximately 40 ksec. The flux for the simulations was set at $4{\times}10^{-11}\,\mathrm{ergs\,cm^{-2}\,s^{-1}}$ in the range 0.1–10 keV. For the HETGS Simulation, one million input photons gave 124,000 output photons for an equivalent exposure time of 36 ksec. In the extraction rectangle, there were 14,000 first order HEG photons and 50,000 MEG. The high-order contribution was about 4% of the first order, and about 50,000 photons went into the zeroth order. With the LETGS, four million input photons resulted in 85,000 detected photons for a 39 ksec equivalent exposure time. The zeroth order had 33,000 photons, and the first order 46,000, with high order contribution about 10% of the first order. Figure 1 shows an expanded view of a portion of the detected HETG image as well as the extracted spectrum.

5.2. Abell 2029 Simulation

The Abell 2029 cluster of galaxies is a bright, nearby (z=0.0767) cluster which is bright in X-rays and contains a strong cooling flow. Such cooling plasmas should be rich in X-ray line emission and make interesting targets for the HETGS. A2029 is, however, an extended object making analysis of its spectrum more involved. The spectrum for the cluster emission was taken from XSPEC fits to ASCA data for this object (Wise & Sarazin 1997, in preparation). The flux for the simulations was taken to be $7.5{\times}10^{-11}\,\mathrm{ergs\,cm^{-2}\,s^{-1}}$ in the range 2–10 keV. The spectral emission was assumed to consist of two components: isothermal cluster emission from a T=7.45 keV Raymond-Smith thermal plasma with an abundance of 0.4 solar and a central cooling flow with M_X=300 $\mathrm{M}_\odot\,\mathrm{yr}^{-1}$.

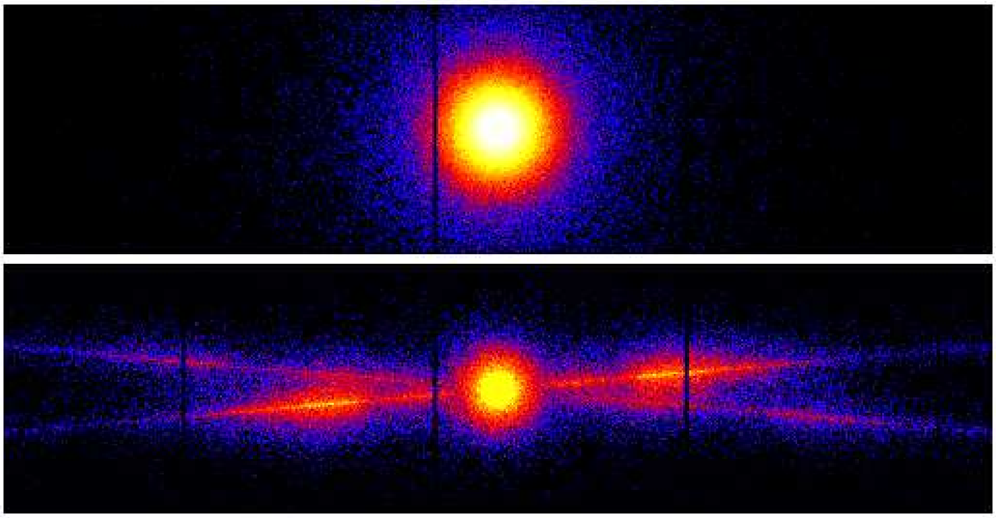

Figure 2. A simulated AXAF observation of the A2029 cluster of galaxies. The lower image depicts an observation utilizing the HETG on-board AXAF while the upper image shows the cluster without the HETG in place.

The cluster emission was assumed to be distributed in a standard spherically symmetric, isothermal beta surface brightness distribution with a core radius of r_c=200 kpc ($\sim$100$''$) and β=0.73 (Sarazin 1986). The cooling flow emission was modeled spatially as a radially symmetric Gaussian with σ=100 kpc ($\sim$50$''$) corresponding to the cooling radius of the flow. A 100 ksec simulated HETG observation yielded 78,000 detected events. The same exposure without the grating in place yielded 218,000 detected events. Figure 2 shows the resulting images from the two simulations.

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