

## An IRAF-Based Pipeline for Reduction and Analysis of Archived ROSAT Data

Katherine L. Rhode, Giuseppina Fabbiano, and Glen Mackie

*Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, MA 02138*

**Abstract.** A pipeline is being developed for the reduction and analysis of ROSAT pointed observations. The pipeline is part of a NASA Long Term Space Astrophysics project entitled “An X-ray Perspective on the Components and Structure of Galaxies” (Fabbiano et al. 1990), and is designed for the purpose of determining structural and spectral characteristics of a large sample of galaxies.

### 1. Introduction

The study of the X-ray spectral and structural properties of galaxies, though still in its infancy, has already proven to be an important area for scientific exploration. During the 1980's, the *Einstein Observatory* provided, for the first time, detailed information about the soft X-ray emission from galaxies. *Einstein* observations led to the discovery of a hot interstellar medium in bright early-type galaxies. They also showed that the X-ray emission from normal spiral galaxies originates in the evolved component of their stellar populations (e.g., supernova remnants, neutron stars, and black holes). In addition, *Einstein* provided data for studies of powerful active galactic nuclei (AGN), and revealed that some otherwise normal galaxies may harbor small-scale, low-luminosity AGN.

The intriguing results from *Einstein* can be substantially expanded using observations from this decade's ROSAT Observatory. The U.S. ROSAT Data Archive at NASA's Goddard Space Flight Center contains data for all non-proprietary ROSAT Position Sensitive Proportional Counter (PSPC) and High Resolution Imager (HRI) pointings. The archive will eventually contain several thousand data sets. To exploit this large volume of data, we are developing a pipeline to systematically reduce and analyze PSPC and HRI observations.

### 2. Details of the Pipeline

In order to utilize the many existing IRAF/PROS tools designed for analysis of ROSAT data, we chose IRAF as the basis of our pipeline. The pipeline's main calling routine is an IRAF script which reads a list of ROSAT observation sequences. The script operates on each sequence in turn, performing step-by-step reduction and analysis of the data. Most of the steps are accomplished with calls to IRAF tasks from the *xray* and *stdas* packages, but the script also invokes

AWK and Unix commands to perform functions such as output formatting and data conversion.

Because of the differing characteristics of the PSPC and the HRI, a separate pipeline script was written for each instrument. Except for a spectral reduction section in the PSPC script, they perform the same basic operations:

- **File Manipulation**

An output directory is created for the sequence; the associated ROSAT archive FITS files are moved there, and used to create IRAF/PROS-format files.

- **Tabulation of Possible Counterparts**

Sky maps and lists of objects in the field are created using the HST Guide Star Catalog (GSC) (Lasker et al. 1990) and the SIMBAD source list from the archive.

- **Image Reduction**

Images are corrected for exposure time and vignetting, and smoothed.

- **Source Detection**

Existence and location of X-ray sources are determined from the IRAF/QPOE event list, using the *ldetect* task (from *xray.xspatial*). (Presently, the pipeline runs *ldetect* once, with a detect cell size of 120".)

- **Flux Determination**

X-ray counts are calculated for SIMBAD and *ldetect* sources.

- **Surface Brightness Profiles, and PSF Derivation**

Surface brightness profiles are derived for sources with  $\geq 300$  net counts, via the *imcnts* task (from *xray.xspatial*).

Appropriate point spread functions are calculated for each *ldetect* source.

- **Spectral Reduction (PSPC version only)**

Spectra are extracted, and hardness ratios calculated, for *ldetect* sources.

For *ldetect* sources with  $\geq 300$  net counts, files are created for input into the XANADU/XSPEC spectral fitting program.

### 3. Pipeline Results and Outputs

The steps described in the previous section yield a set of output files for each ROSAT observation that includes:

- **Image Analysis**

Smoothed images and contour maps

Surface brightness profiles for selected *ldetect* sources

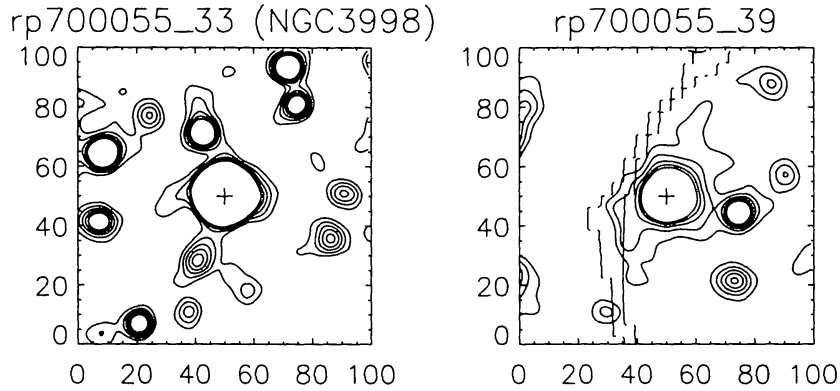


Figure 1. X-ray contour maps, made by passing pipeline output to IDL routines. Each square is a 100x100-pixel (15" x 15") sub-image of the NGC 3998 field, centered on an *ldetect* source. 59 sources were detected in this field using a detect cell size of 120"; source 33 (the field target) and 36 are shown. The solid lines are X-ray contours at 2, 4, 6, 8 and 10 $\sigma$  above background; broken lines indicate portions of the field obscured by the PSPC support structure.

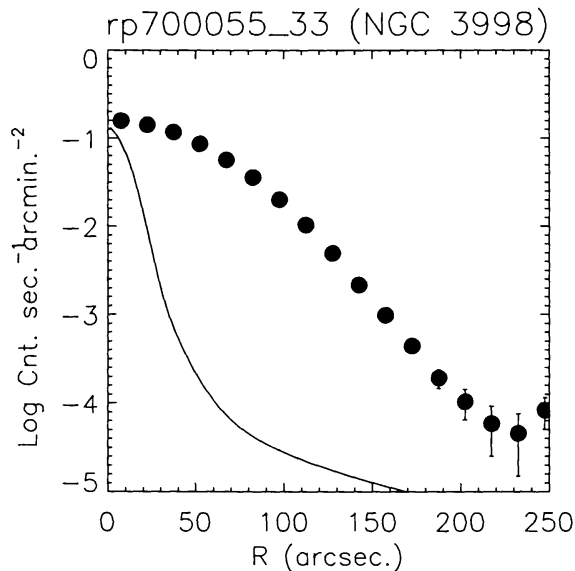


Figure 2. The X-ray surface brightness profile produced by the pipeline for *ldetect* source 33 (NGC 3998). The profile is plotted as filled circles; the line is the 1.4 keV PSPC point spread function.

- **Spectral Analysis (PSPC data only)**  
Extracted spectra for *ldetect* sources, in IRAF/PROS and XSPEC format
- **Files for Plotting and Graphics**  
Plots of GSC objects (stellar and non-stellar) in the field  
Input files for specialized IDL graphics routines
- **Other**  
A log of each IRAF command, with the date and time of execution  
Final results, tabulated in Unix */rdb* databases

Example pipeline output for ROSAT sequence rp700055, a 58.5 ksec PSPC observation centered on the S0 galaxy NGC 3998, is shown in the figures.

#### 4. Planned Improvements to the Pipeline

The first version of the pipeline was completed in September 1993. As we begin processing data from the archive, we are also “fine-tuning” the pipeline, and expect to complete a second version by early 1994. Along with other improvements, future versions will permit:

- Preliminary spectral fitting on some sources, performed automatically with XANADU/XSPEC (PSPC version only)
- Calculation of X-ray color ratios (PSPC version only)
- Incorporation of overlays of the CD-ROM ST ScI Guide Star (Digitized Schmidt Plate) Survey, when it becomes available
- More accurate background subtraction, using templates from long-exposure PSPC and HRI frames
- Cross-correlation of X-ray source positions with positions in catalogs such as the Third Reference Catalogue of Bright Galaxies (de Vaucouleurs et al. 1991), and the Catalogue of Principal Galaxies (Paturel et al. 1989)

**Acknowledgments.** This work was supported in part under NASA grant NAGW-2681(LTSA).

#### References

- Fabbiano, G., Canizares, C. R., Kim, D.-W., Schechter, P., & Trinchieri, G. 1990, NASA Long-Term Space Astrophysics Research Program Proposal P2309-10-90
- Lasker, B. M., Sturch, C. R., McLean, B. J., Russell, J. L., Jenkner, H., & Shara, M. M. 1990, *AJ*, 99, 2019
- Paturel, G., Fouque, P., Bottinelli, L., & Gouguenheim, L. 1989, *A&AS*, 80, 299
- de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Buta, R. J., Paturel, G., & Fouqué, P. 1991 Springer-Verlag: New York