IMAGING, PSFs, DECONVOLUTION

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1. Exploring Multi-scale Structures in Chandra Images

Chandra images contain structures at many different spatial scales. In order to enhance, detect and study these structures we apply different methods, including:

- **adaptive smoothing (eg. Ciao tool csmooth)**
- **detect (eg. Ciao tool wavedetect)**
- **deconvolution methods (Richardson-lucy and other deconvolution techniques).**

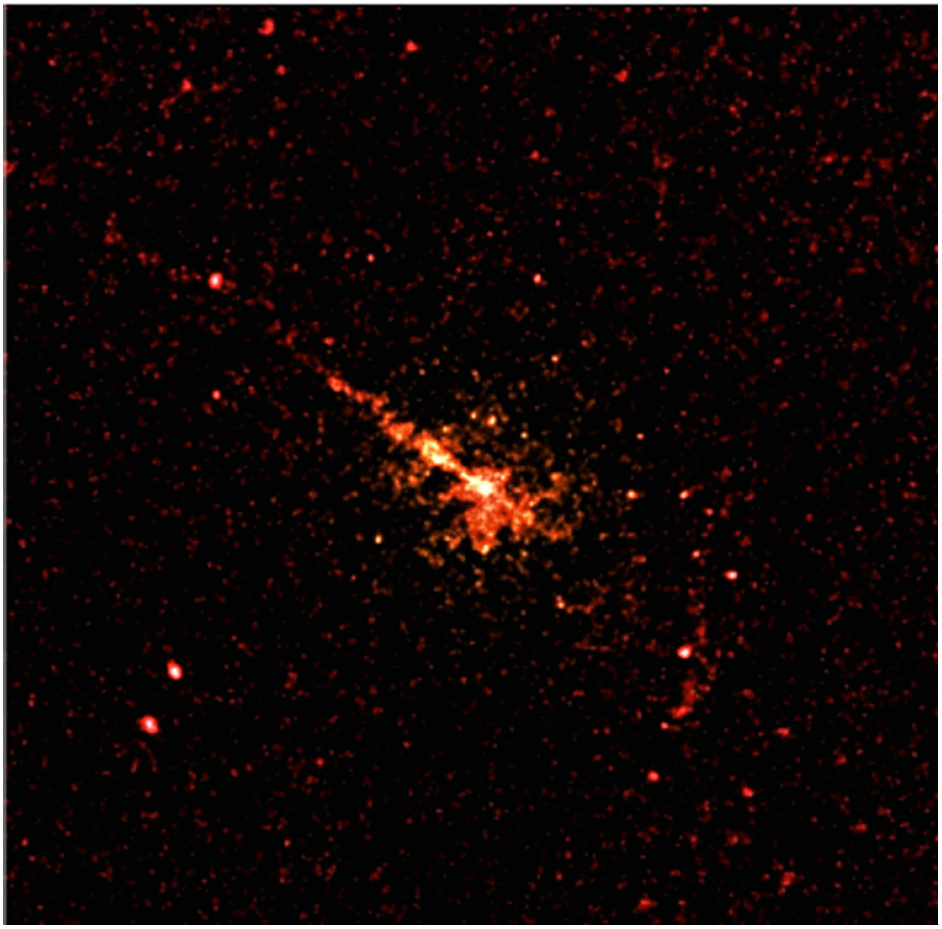

Fig. 1.— HRC-I image of Cen A showing multiscale spatial structures

1.1 Adaptive Smoothing of Cen A

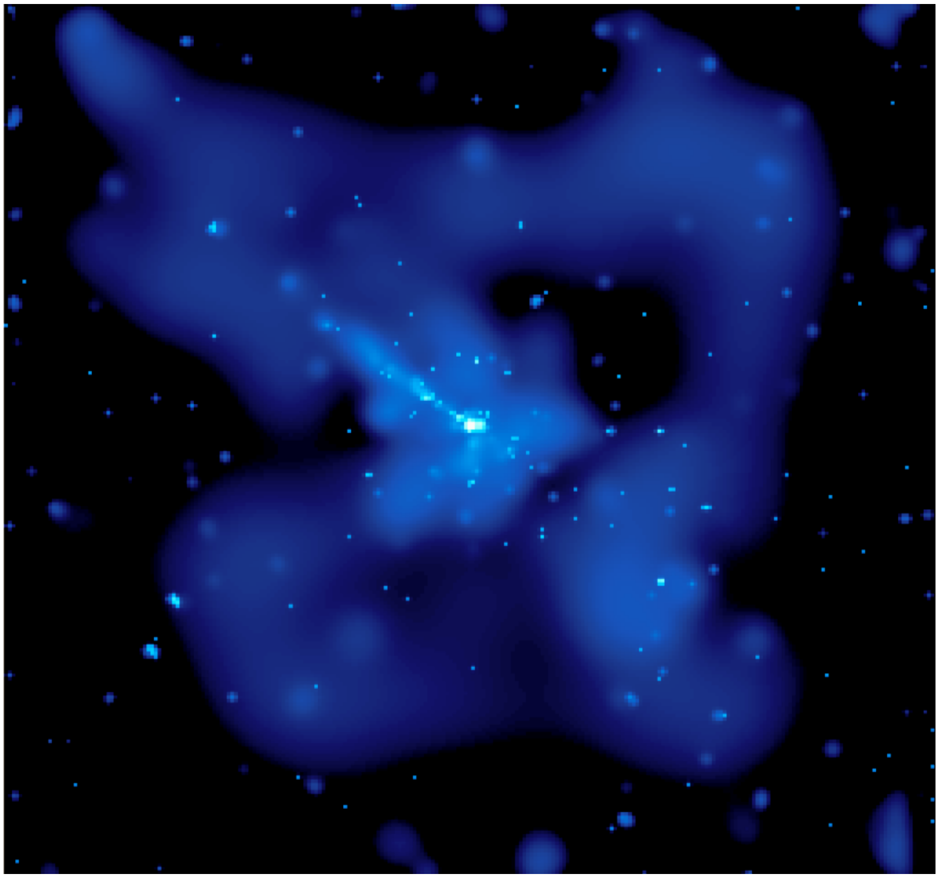

Fig. 2.— Adaptive smoothing of the HRC-I Cen-A image (Fig. 1) shows faint diffuse emission from two arcs at large scales (≈ 8', 8kpc from the nucleus) (Karovska et al. 2000, Ap.J., 577, 114).

1.2 High-angular Resolution Imaging

Chandra produces sharper images than any other X-ray telescope to date and therefore provides an opportunity for high-angular and spectral resolution studies of X-ray sources. Crucial to these studies is the knowledge of the characteristics of the PSF. The blurring of the Chandra PSF is introduced by the HRMA PSF, the aspect, the limited size of detector pixels and detector effects. Simulating the HRMA PSF is the first and most important step in obtaining a good model of the Chandra PSF for a given observation.

The shape and size of the HRMA PSFs vary significantly with source location in the telescope field of view (FOV), as well as with the spectral energy distribution of the source. Therefore, in order to carry out spatial analysis of the *Chandra* **data each PSF must be simulated individually.**

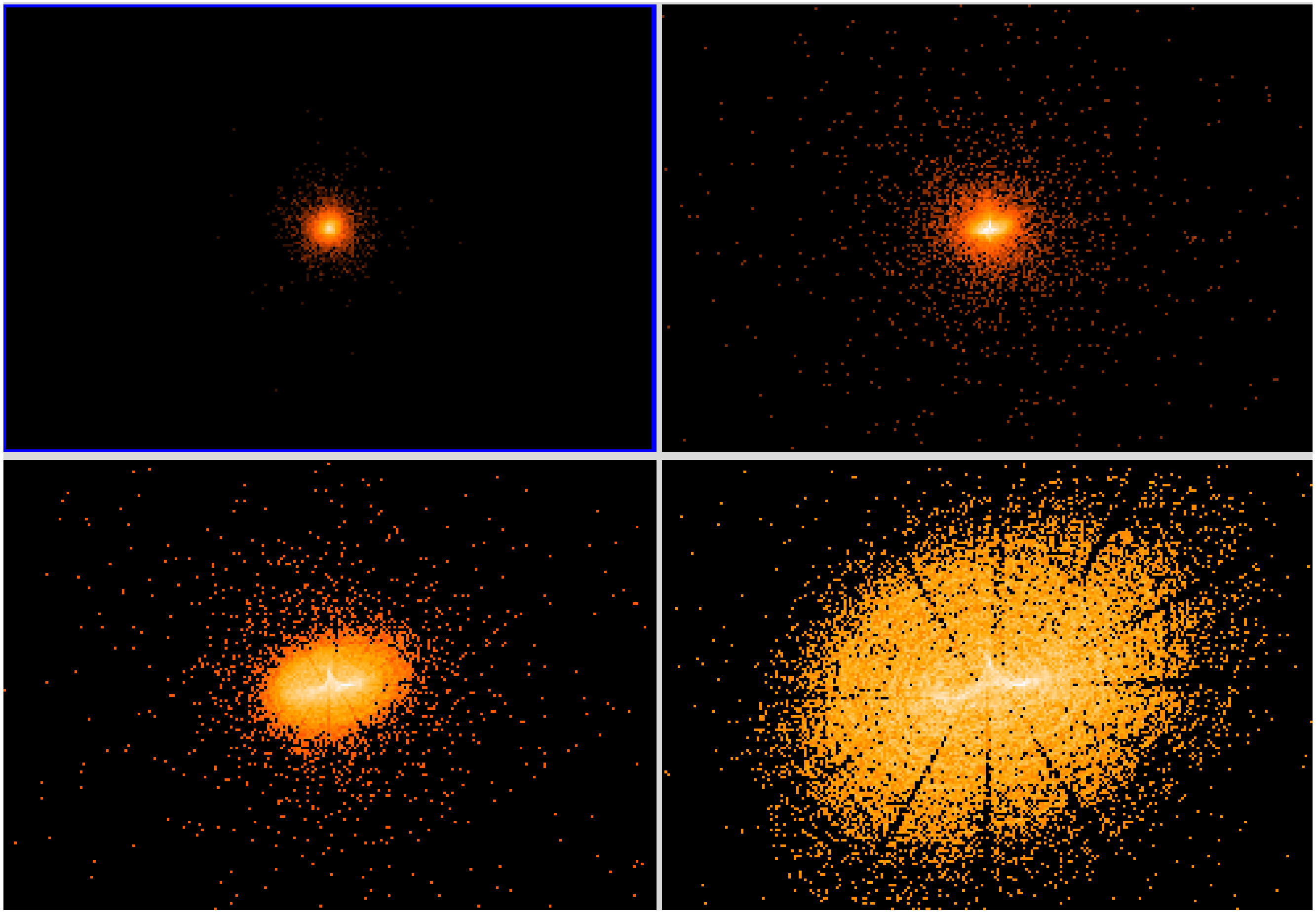

Fig. 3.— Monochromatic (1.5 keV) HRMA PSFs on-axis, and at several off-axis angles (θ= 2', 5', 10', and ϕ=0)

ChaRT (Chandra Ray Tracer) is a user friendly web interface that allows the user to simulate High Resolution Mirror Assembly (HRMA) Point Spread Functions (PSFs) at any off-axis angle and for any energy or spectrum. Realistic PSFs including instrument effects can be simulated using the ChaRT ray files as an input in MARX.

http://cxc.harvard.edu/chart/

- *Why ChaRT rather than the standard PSFs libraries?*

The standard PSF library files consist of 2-D simulated monochromatic PSF images "postage stamps" (only for 5 monochromatic energies ranging from 0.277 keV to 8.6 keV), made using SAOsac and projected onto ideal detector planes. They are stored in multi-dimensional FITS hypercubes with az and el steps (in telescope fixed system) of either 1 arcminute or 5 arcminutes. The user can extract a PSF model image from a library file by interpolating within the energy and off-axis angle grids, using *mkpsf***.**

The usage of the standard PSFs libraries (with *mkpsf*) for a detailed spatial/spectral analysis has limitations including:

- **interpolation over the coarse energy and spatial grids, especially for large off-axis angles.**
- **monochromatic energies only**
- **number of photons (rays) fixed**
- **no instrument effects included**

2. ChaRT Overview

- **ChaRT provides the user with access to the best available mirror model, including many of the details of the HRMA's physical construction and a detailed model of the reflective properties of the mirror surface.**
- **ChaRT runs remotely the *SAOsac* set of routines (used internally at the CXC for studies and calibration of the HRMA optics).**
- **The s/w verifies and submits user's simulation parameters and notifies the user when their files are available for download via FTP.**

The output of ChaRT is a FITS table containing a collection of rays. In order to create a model PSF image it is necessary to project the rays onto the detector and take account of detector effects. This is achieved using The ChaRT rays as an input to MARX.

A set of ChaRT threads accessible from the ChaRT web page were designed to guide the user

http://cxc.harvard.edu/chart/threads

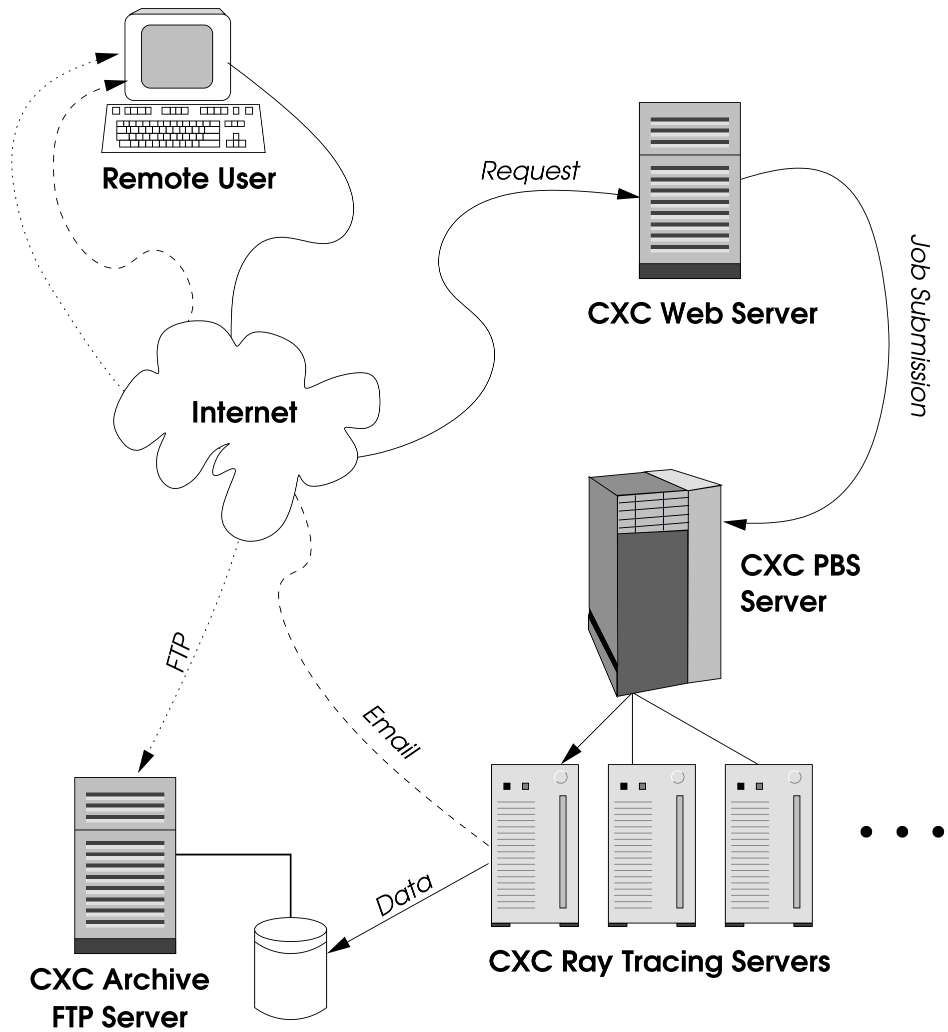

Fig. 4.— ChaRT software and hardware architecture

2.1 ChaRT Web Pages

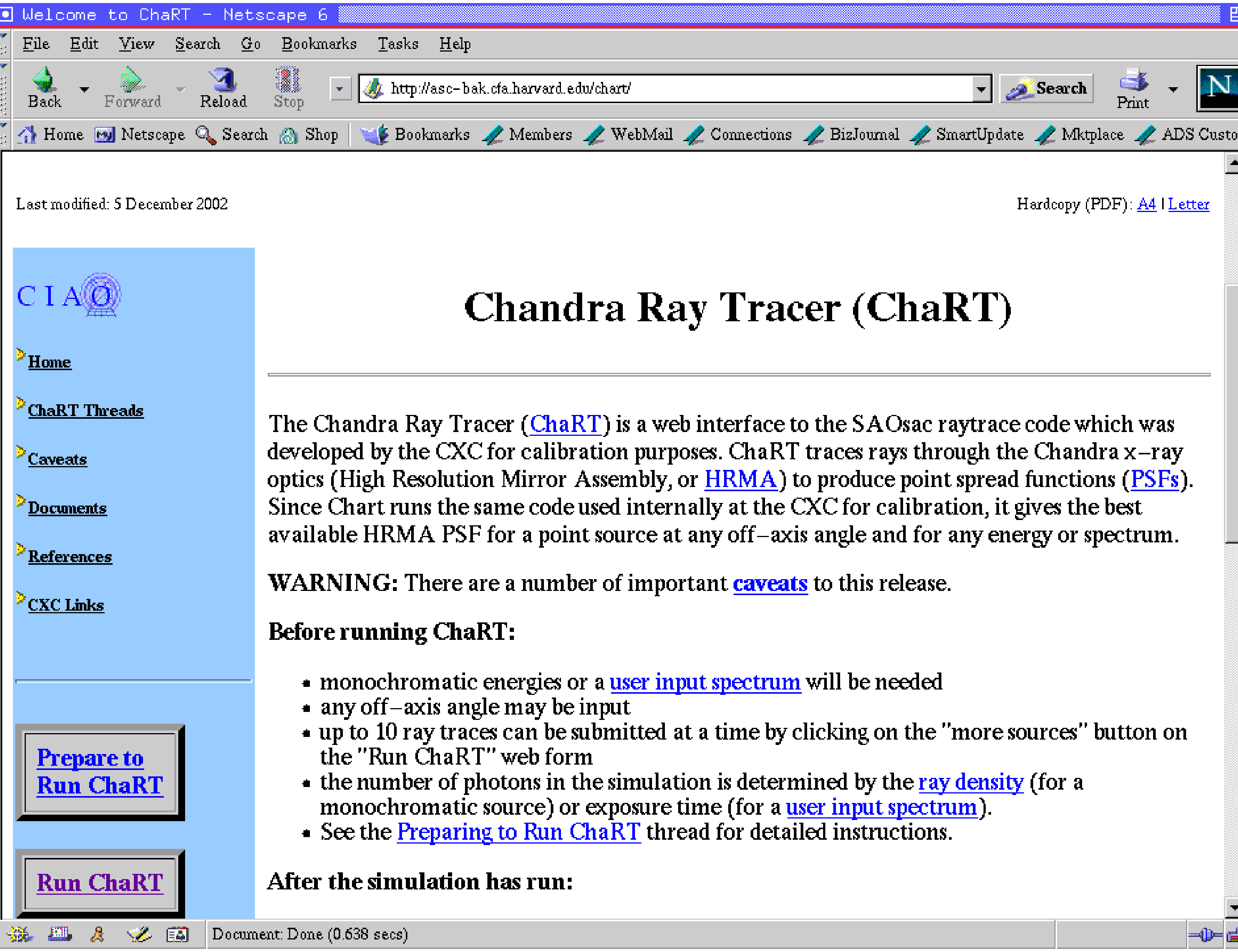

Fig. 5.— ChaRT web page - 1

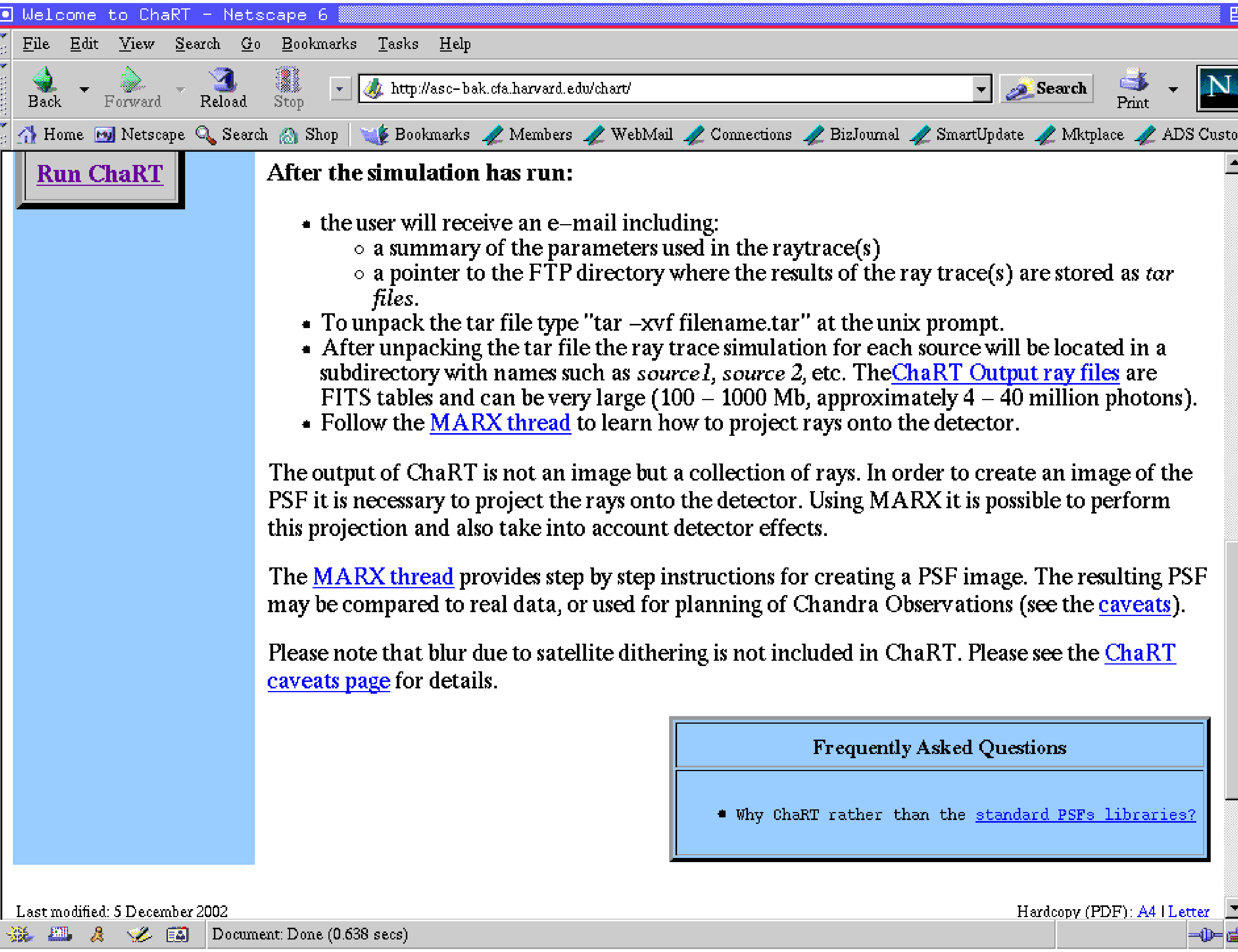

Fig. 6.— ChaRT web page - 2

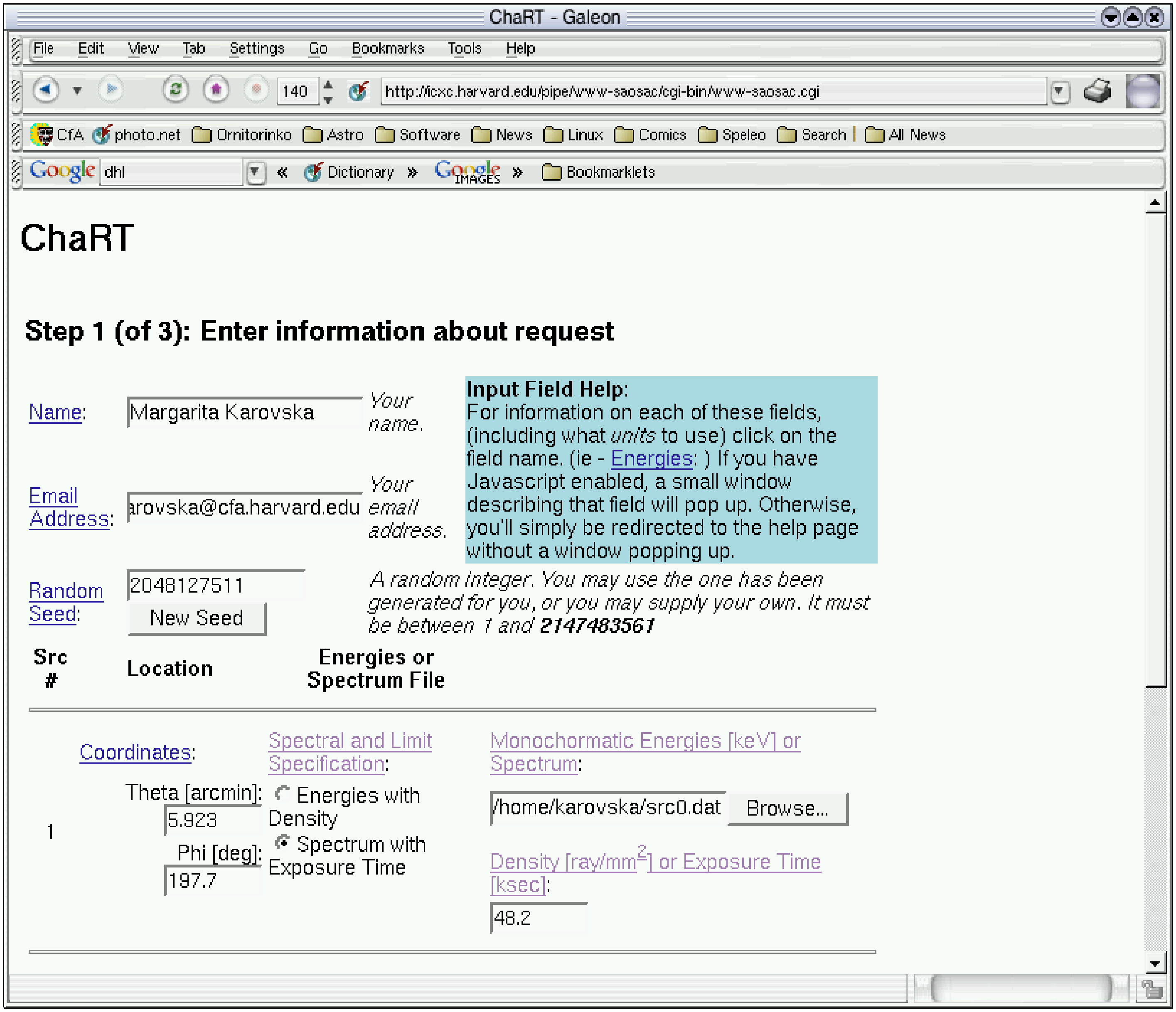

Fig. 7.— ChaRT parameter interface

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From: ChaRT <cxc_rays@head-cfa.harvard.edu>
Message-Id: <200212122036.PAA13443@young.cfa.harvard.edu>
Content-Type: text

Your job has completed.  You may retrieve your files from our
anonymous ftp data server, where they will be stored for no more then
2 days.  Pertinent information is listed below.  Thank you.

===[ This is an automated email.   Do not respond to this address. ]===
===[ If you need help, please contact cxchelp@head-cfa.harvard.edu ]===

Host: cda.cfa.harvard.edu
Username: anonymous
Password: karovska@cfa.harvard.edu
Directory: /pub/traceftp
Filename: karovska-20021212-153643.tar.gz
File size (approx, untarred, [MiB]): 0
URL: ftp://cda.cfa.harvard.edu/pub/traceftp/karovska-20021212-153643.tar.gz
Job Parameters:

Name  = Margarita Karovska
Email  = karovska@cfa.harvard.edu
Random Seed  = 1337910590

Source 1

Coord Sys  = Theta/Phi
Theta [arcmin]  = 5.923
Phi [degree]  = 197.7
Spectrum  = src0.dat
Exp. Time [ksec] = 48.2
```

Fig. 8.— E-mail to the user

3. Examples

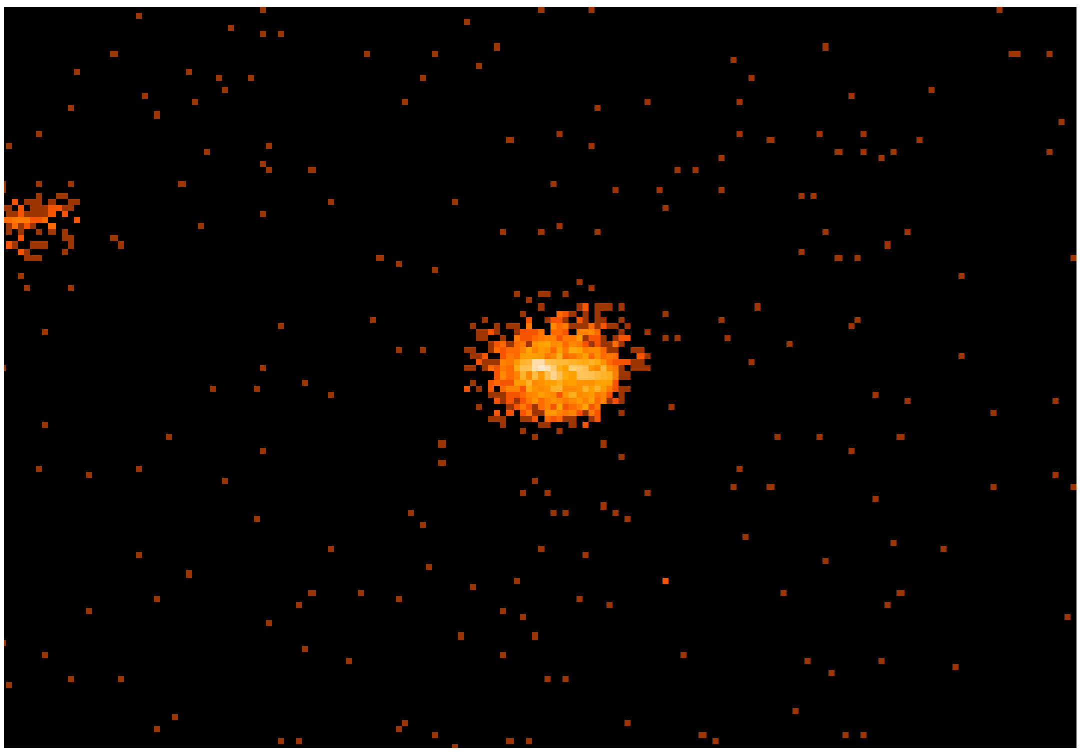

Fig. 9.— ACIS-S observation of a source at 6' off-axis angle (source 1)

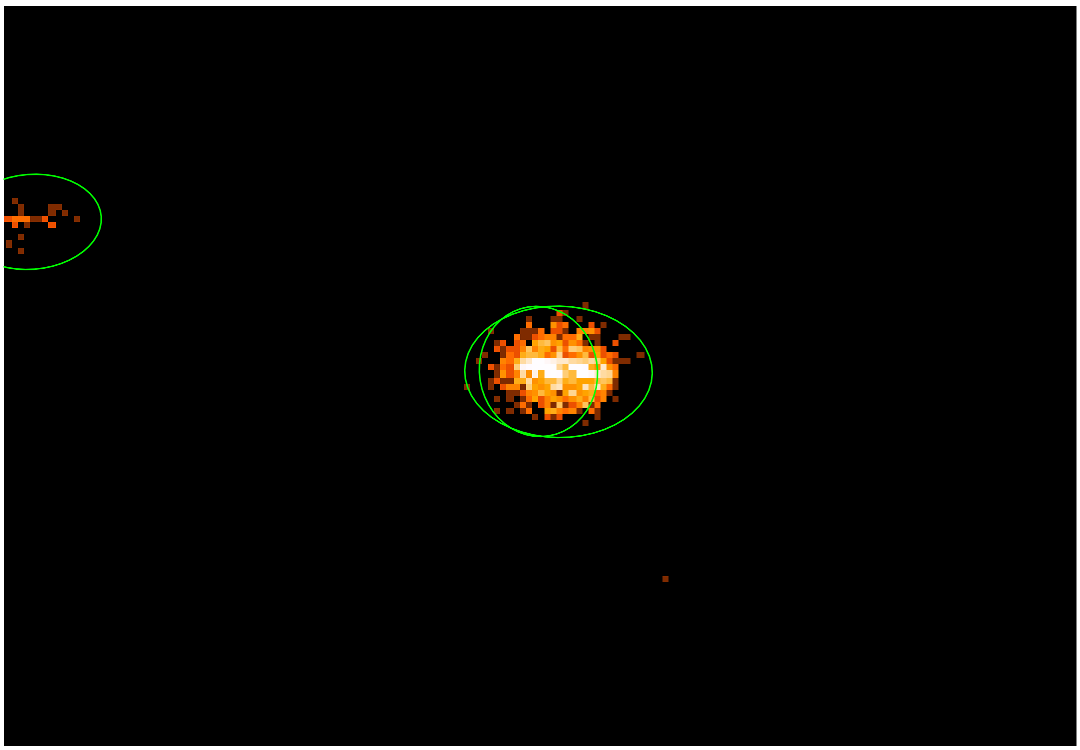

Fig. 10.— Wavedetect result for source 1

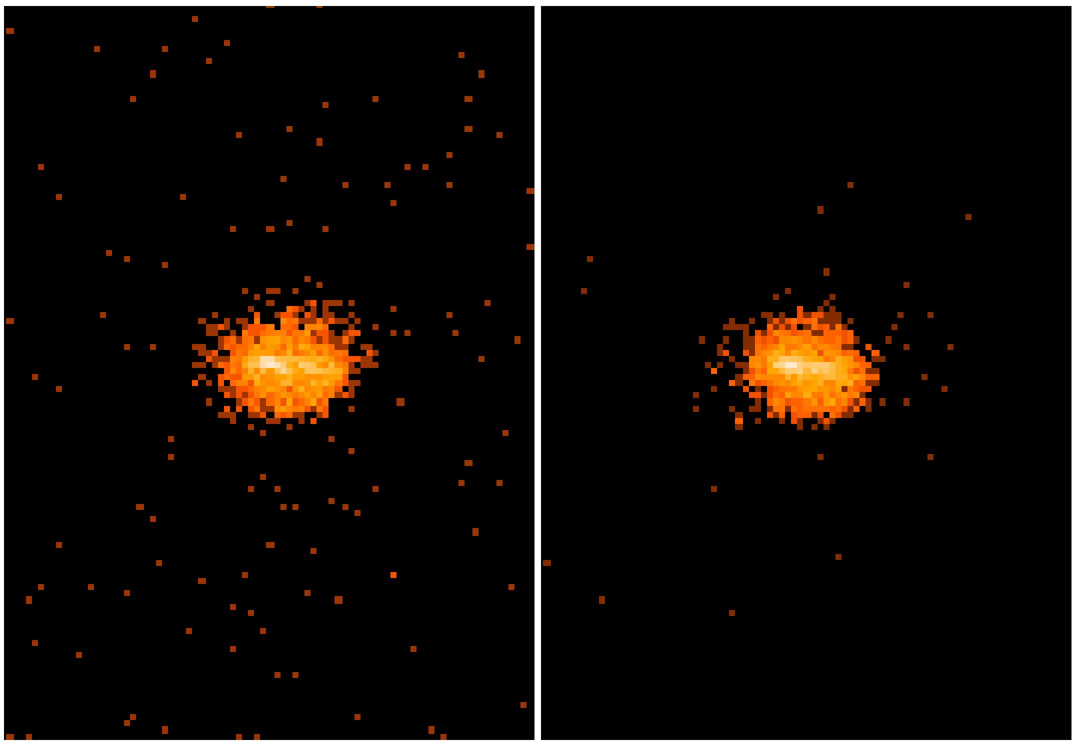

Fig. 11.— Source 1: observation vs. PSF

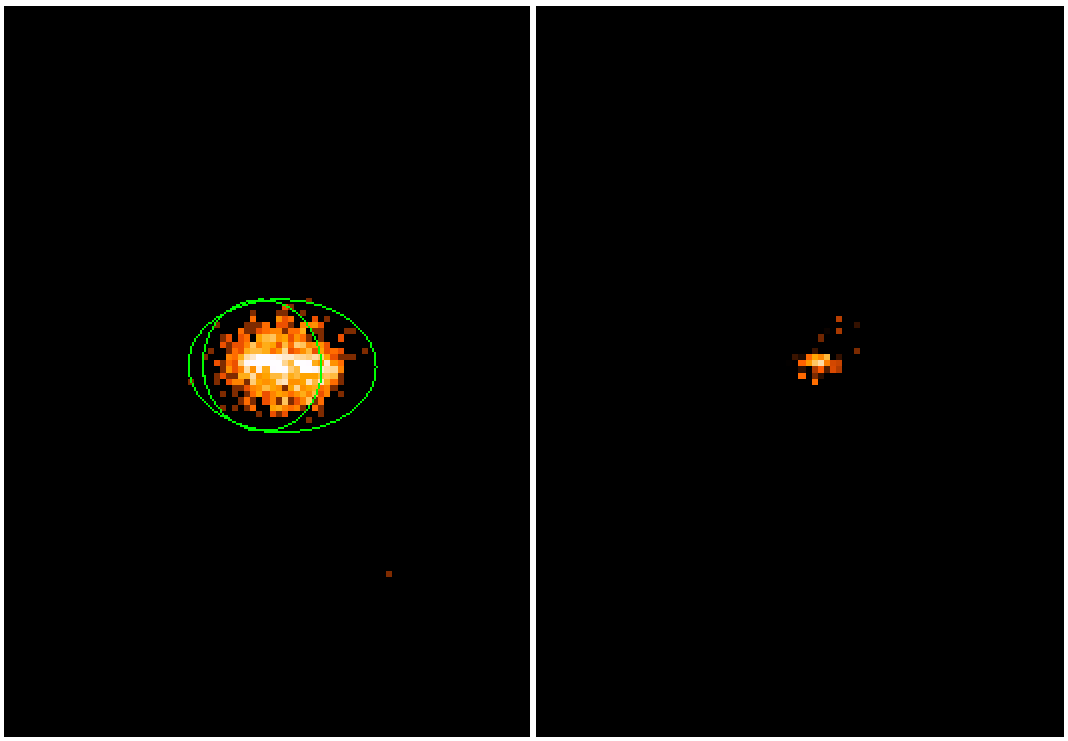

Fig. 12.— R-L deconvolution of source 1 with ChaRT PSF

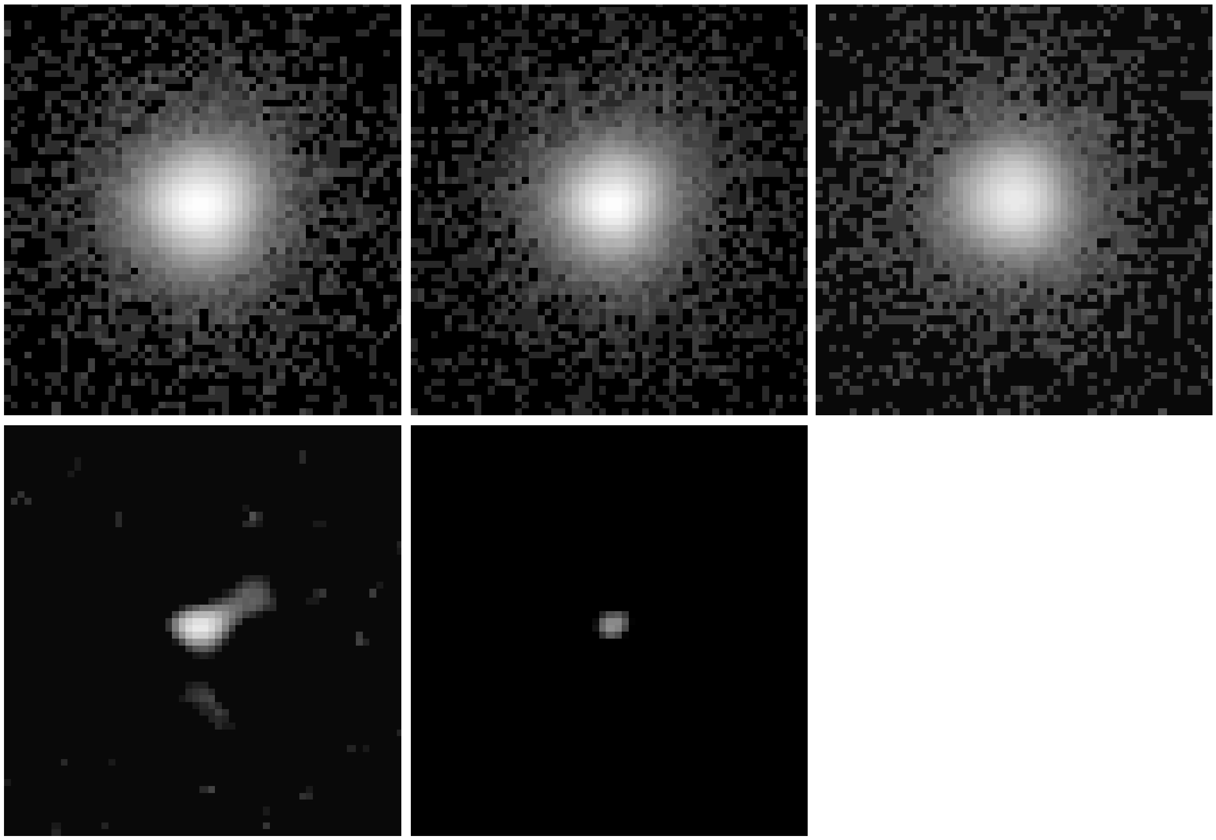

Fig. 13.— HRC-I observation of AR Lac (20” off-axis). Clockwise from the left: AR Lac original HRC-I image; AR Lac image “corrected” for the HRC blur (D. Jerius, 2002); ChaRT/MARX simulated PSF obtained using AR Lac spectrum; AR Lac original image deconvolved with the ChaRT/MARX PSF; AR Lac “corrected” image deconvolved with the ChaRT/MARX PSF.