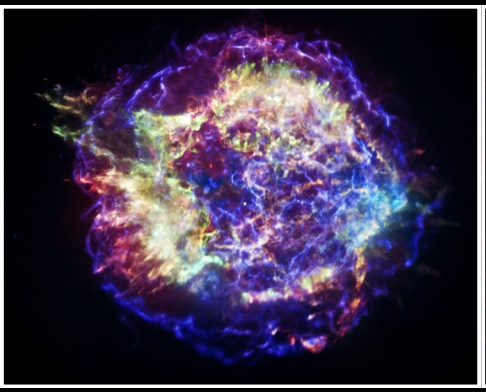
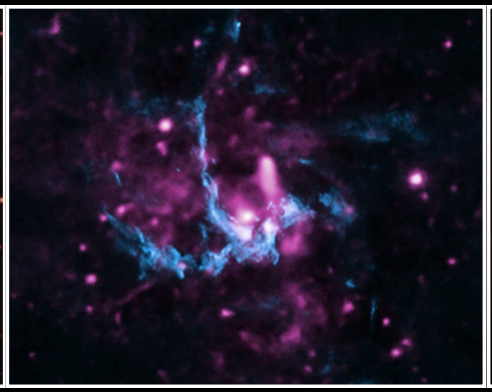
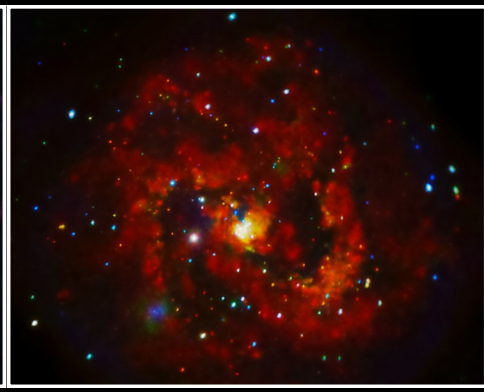
2014 Senior Review

CHANDRA X-RAY OBSERVATORY

Jonathan McDowell
CXC Science Data System
2014 March 24



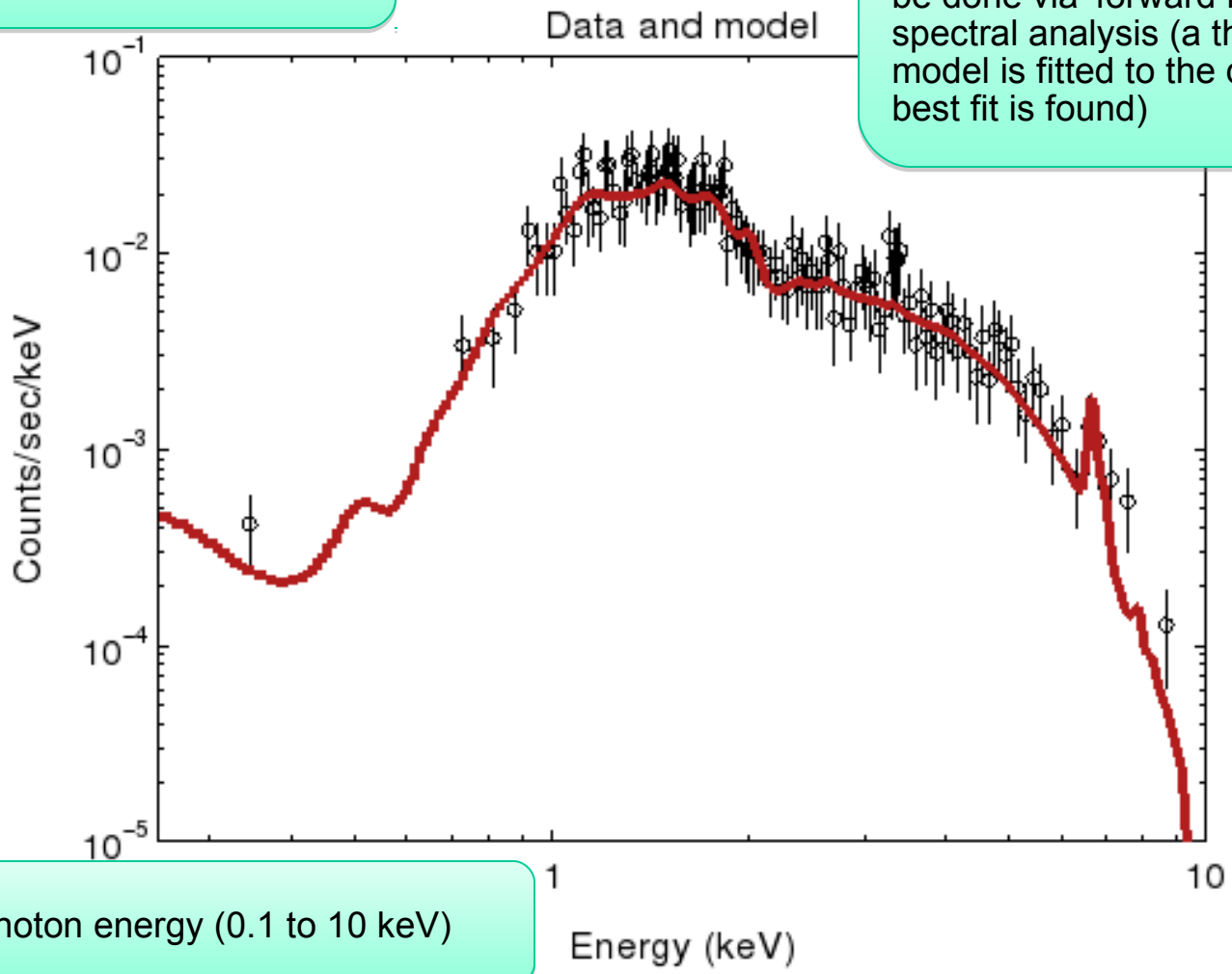
CIAO

Chandra Interactive Analysis of Observations

Complexities in X-Ray and Chandra Data Analysis

In Poisson statistic regime because of the small number of photons

Imaging data has limited energy resolution and modeling can only be done via 'forward folding' spectral analysis (a theoretical model is fitted to the data until the best fit is found)



2 decades of photon energy (0.1 to 10 keV)

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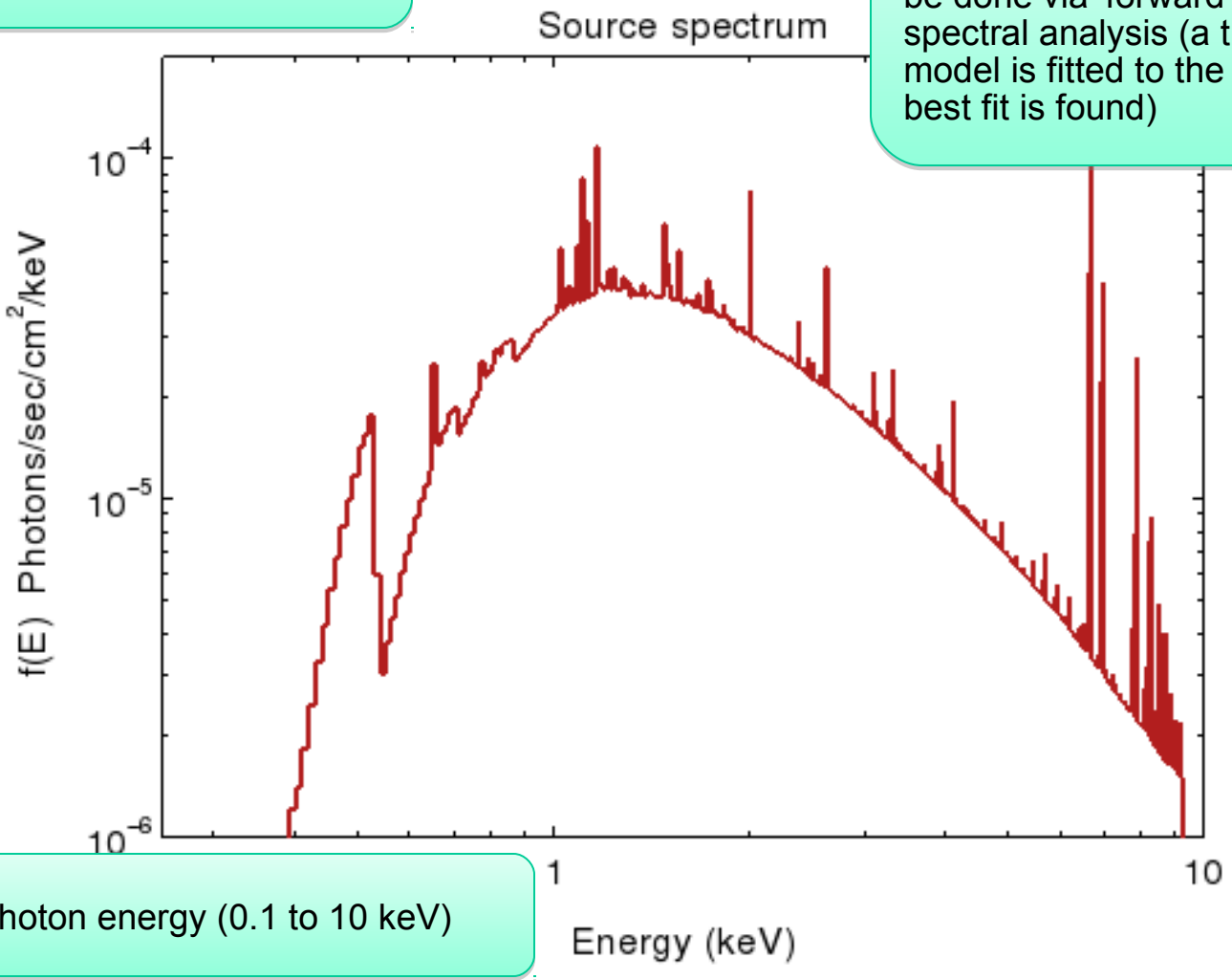


2 decades of photon energy (0.1 to 10 keV)

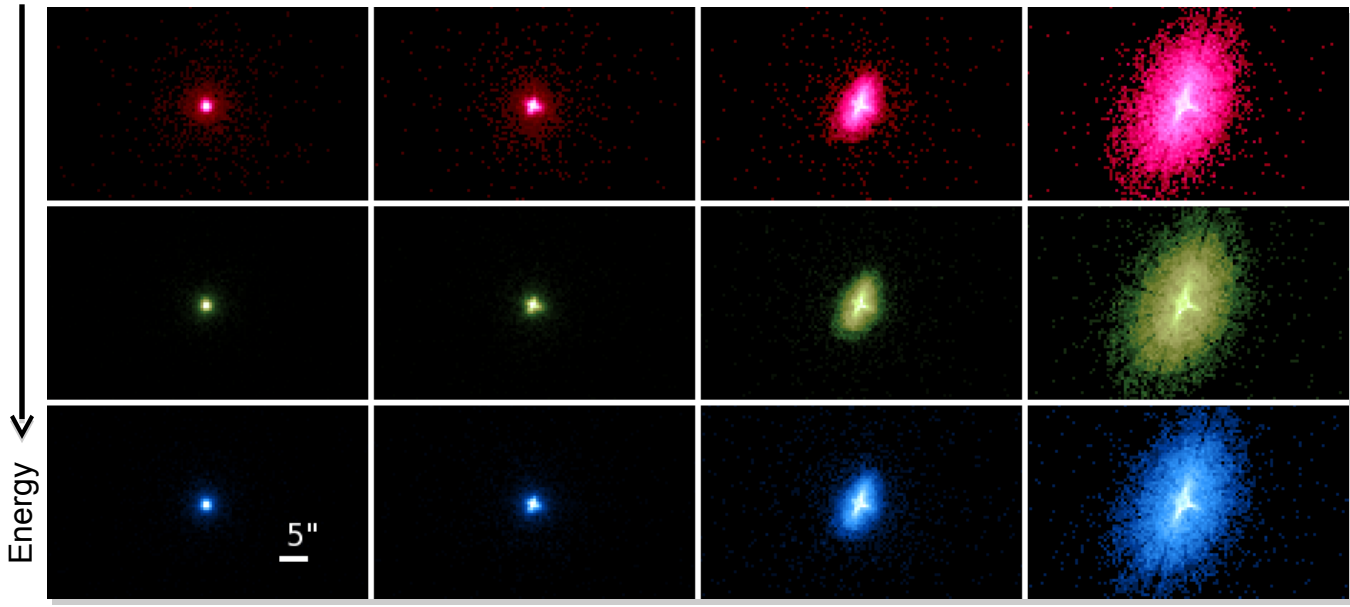
Complexities in X-Ray and Chandra Data Analysis

Every aspect of the observation varies with

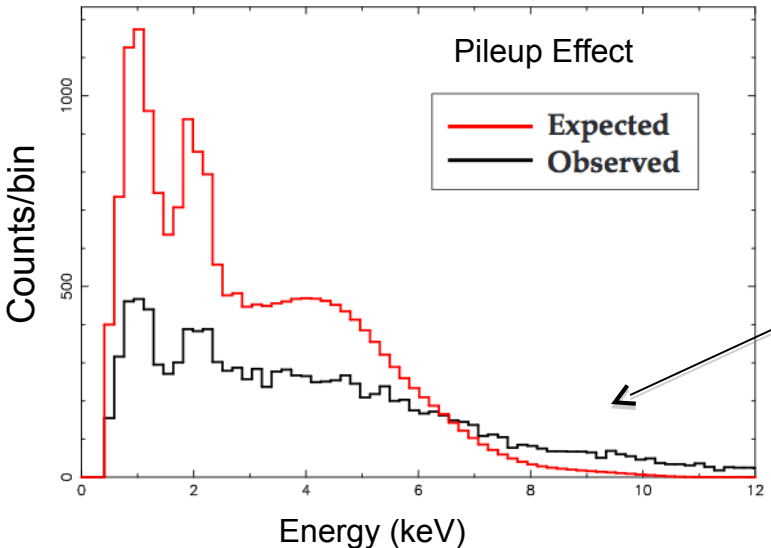
- **energy**
- **position**
- **time**

(e.g. image sharpness, sensitivity, instrumental energy scale)

The Chandra PSF



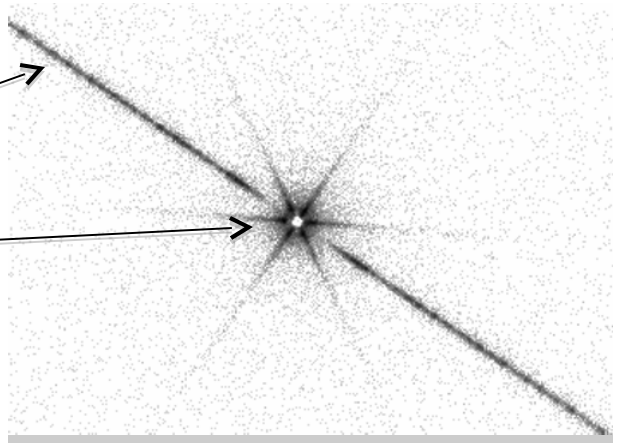
Q0836+7104 predicted vs. observed



Specific instrumental effects eg.

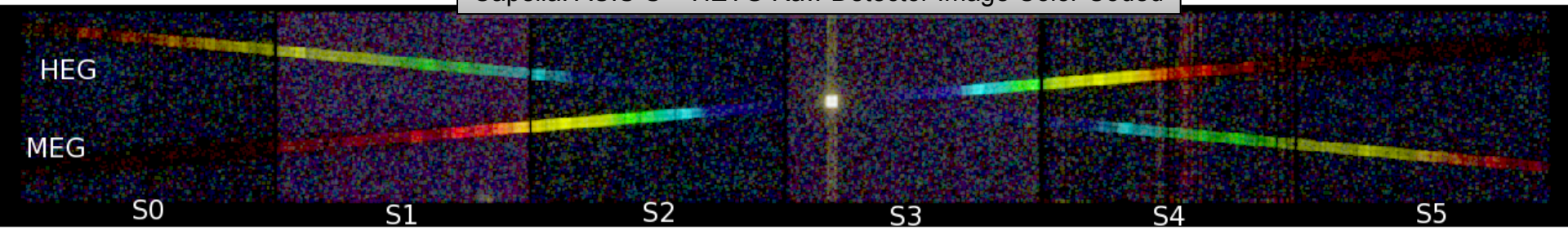
readout streak

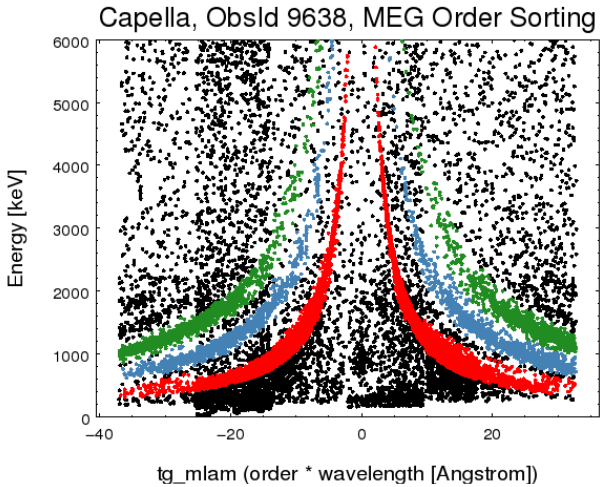
pileup - two or more photons detected as single event

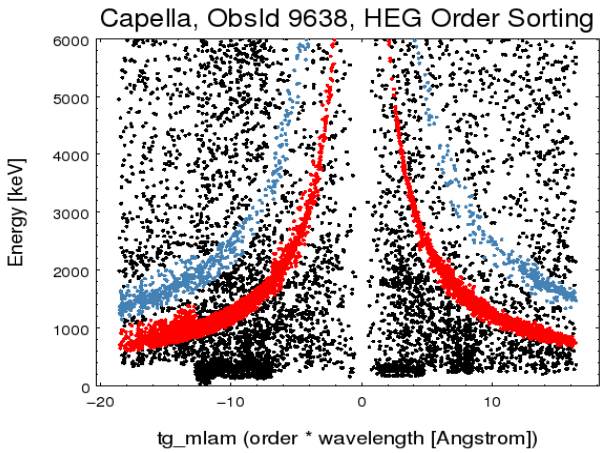


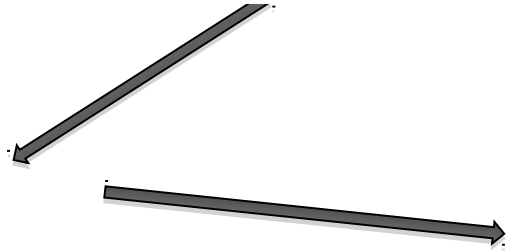
Complexities in X-Ray and Chandra Data Analysis

Capella: ACIS-S + HETG Raw Detector Image Color Coded

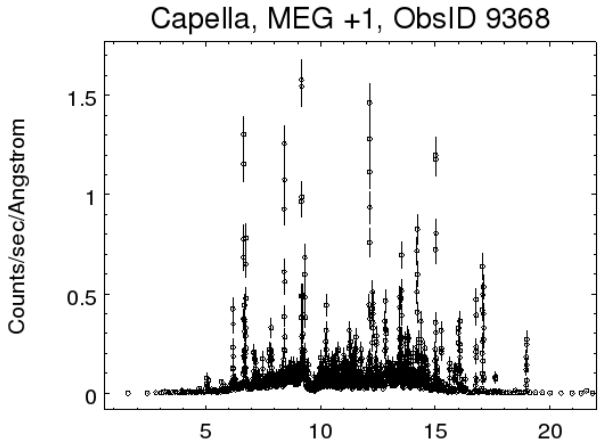


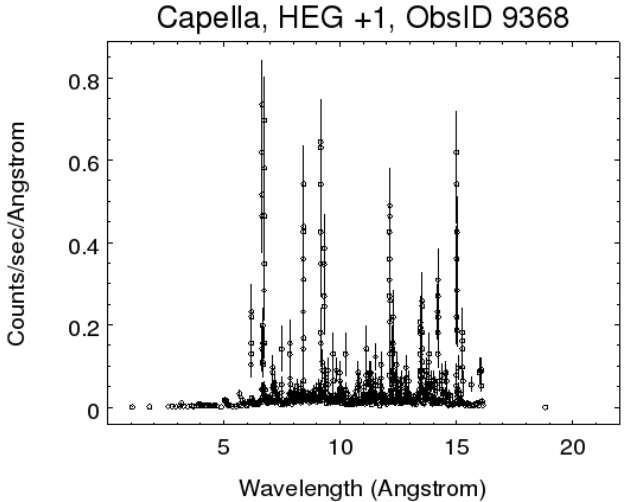






- overlapping spectral orders separation
- complicated geometry – need precise zero order location
- wavelength scale sensitive to details of chip geometry
- background different on each chip





Chandra Users

We support users of Chandra data from around the world

- Both experienced and novice X-ray astronomers
- their graduate and undergraduate students
- archival users, many new to X-ray/Chandra data
- users with a large amount of resources and users from smaller countries and institutions

users with different science goals …

- estimate the X-ray flux of my favorite object
- model fitting to spectrum to get velocity (line width) of material
- model fitting spectrum to find gas temperature, pressure in 100 different galaxies
- assess reality of a marginal detection (3 photons at the position of a gamma-ray burst)

…. and with widely varying datasets

- 20 minutes to 2 days (or even 1 month for coadded data)
- different configurations (chips, subarrays, gratings, special instrument settings)
- different targets (pointlike stars and quasars, fuzzy galaxies and clusters, moving solar system objects)

All this requires a wide variety of specialized software AND careful documentation

CIAO – *Chandra Interactive Analysis of Observations*

- → A set of Unix command line tools and Python applications
- → Shares code with standard processing pipeline
- → Allows Chandra instrument specific data reduction
- → Tailored to specialized X-ray astronomy data analysis, but not specific to Chandra
- → Coded with attention to standards and interoperability so that generic tools can be (and are!) used for XMM, Nustar, and even optical and radio data (e.g. multiwavelength analysis)
- → Easy for beginners, yet powerful for advanced users
- → Linux and Mac, annual releases
- → Installed 1200+ times per year (single users to large institutions)

CIAO: supports users from proposal to publication

Tools for proposal planning
Assessing feasibility and examining Chandra field-of-view

→ e.g. *obsvis, colden*

Tools for data discovery and access
Command line programs to complement the Archive and Catalog searches

→ e.g. *find_chandra_obsid, download_chandra_obsid, search_csc*

Tools for data inspection and exploration
What is this dataset? How many photons? What instrument configuration? Quick look visualization...

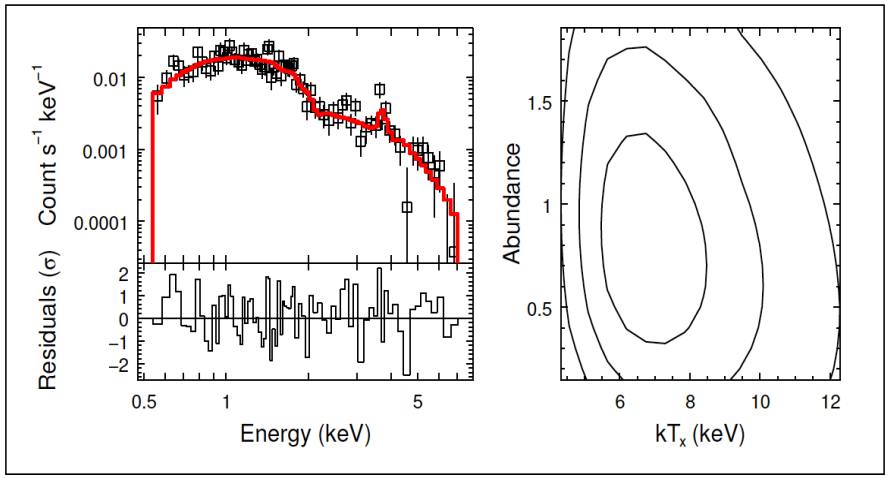
→ e.g. *ds9, prism, dmlist, dmstat, dmcopy*

Tools for data reduction
Apply latest calibrations to observation
Locate sources and measure their properties (position, brightness)
For each source, generate tailored calibration files (e.g. spectral calibration)

→ e.g. *dmextract, wavedetect, specextract, srcflux, fluximage*

Tools for interactive data analysis
'sherpa' – 1D and 2D modeling and fitting
Python environment – familiar to the new generation of astronomers and used in other missions

Tools to prepare for publication
'ChIPS' – publication quality graphics integrated with the analysis system



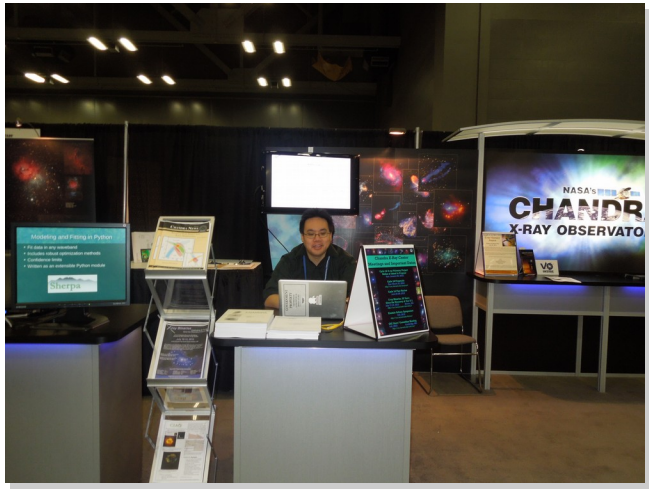
Documentation and Community Support

Documentation

- Science-task-oriented step-by-step, end-to-end analysis 'threads' (170+)
- 1000 help files for individual tools, concepts
- Over 2000 web pages including FAQ, plot galleries, dictionaries, caveats and bug notes etc.
- You Tube tutorials

Helpdesk

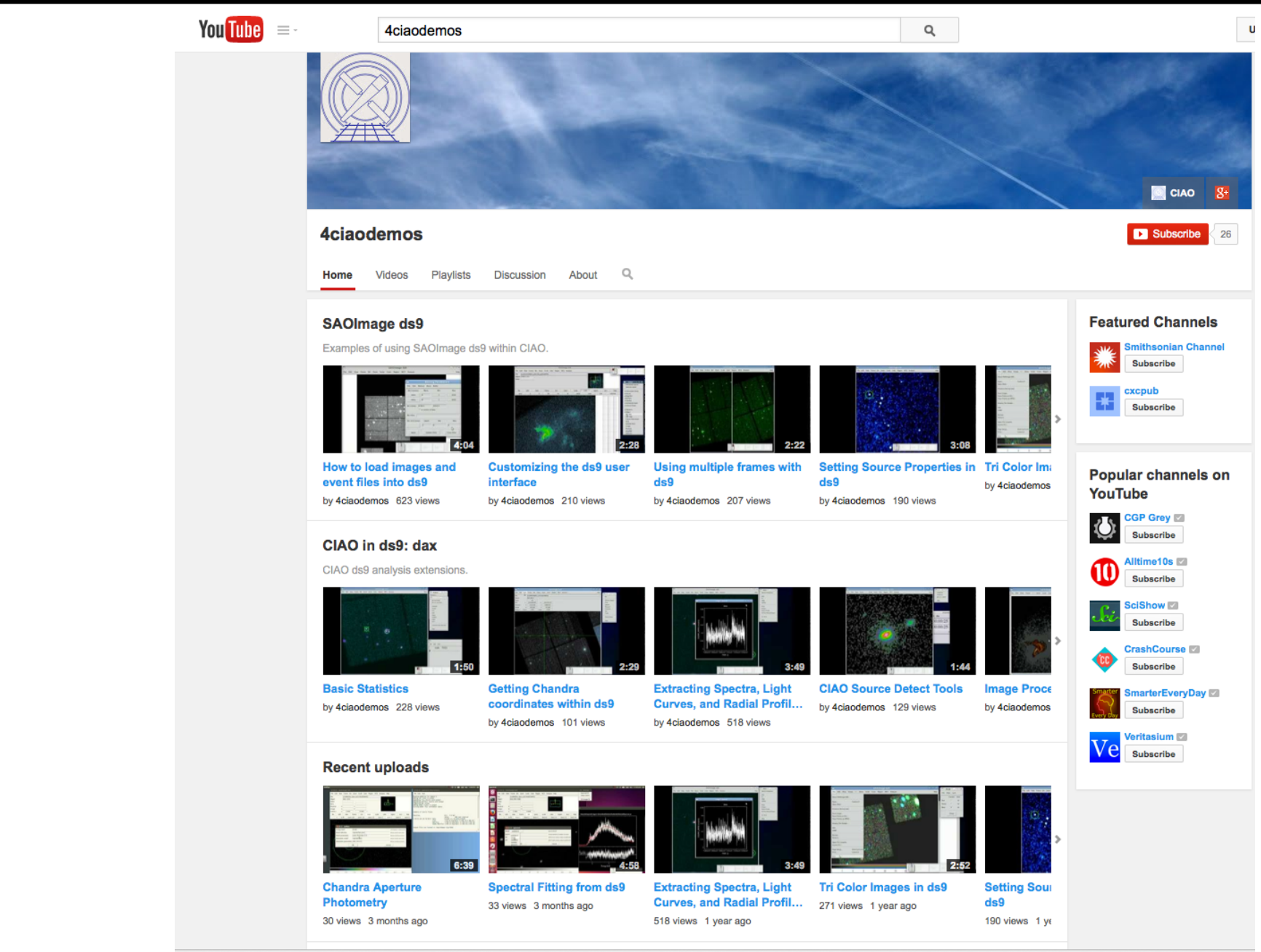
- About 450 CIAO tickets last year from all over the world
- Median time to respond 1 hour, to resolve 1 day
- Experienced help desk staff backed up by SDS scientists and other CXC staff when needed



One-on-One Community Support

- Chandra/CIAO Workshops hosted at CFA
- CIAO education and support at relevant meetings (e.g. X-ray schools, AAS)
- Undergraduate training via NSF REU program at SAO

You Tube Tutorials



Maintenance and Responding to Change

Critical maintenance

updates to keep up with changes in spacecraft and/or instruments → eg. modify analysis tools to support temperature variation, combining shorter observations

support changes in users' hardware and operating systems → eg. Dec Alpha to Solaris to Linux to Mac

Address users' needs if/as resources allow…

support changes in users' needs (2014 is not 1999), incorporate changes in scientific approaches and computational approaches; compatibility with newer missions → eg. Bayesian methods, parallel processing

incorporate improved knowledge of best practices and special cases – enhance science, minimize mistakes → eg. applying custom background region for grating spectra

identify and prioritize areas needing additional support →

eg. merging datasets split due to new thermal constraints

analysis tools for extended sources

support for alternate instrument configurations (e.g. continuous clocking readout mode)

CIAO scripts: analysis simplified

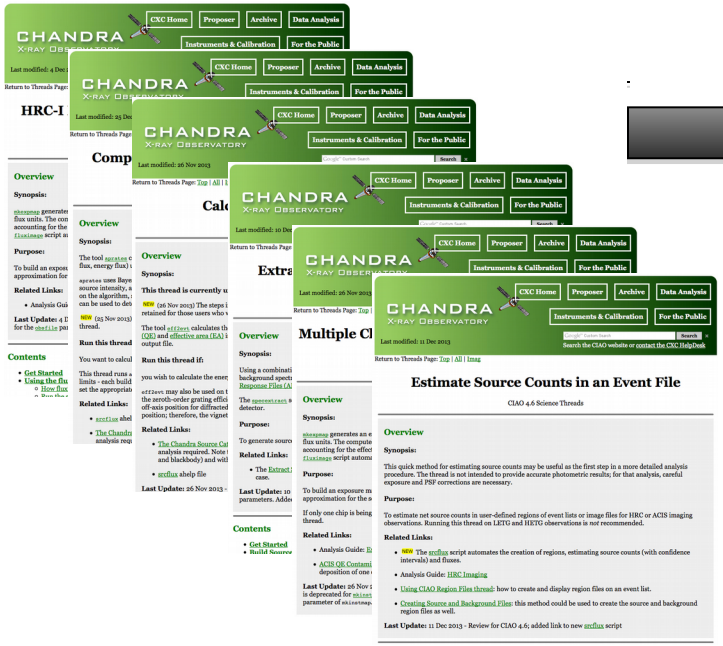
Recent emphasis on high level programs with easy interfaces – particularly helpful for users who are not X-ray astronomy specialists.

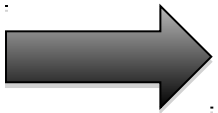
Wrap laborious thread analysis steps with a single command line script

Handle the various special cases by inspecting the metadata in the data files

Scripts have parameters which allow the expert user to tune them

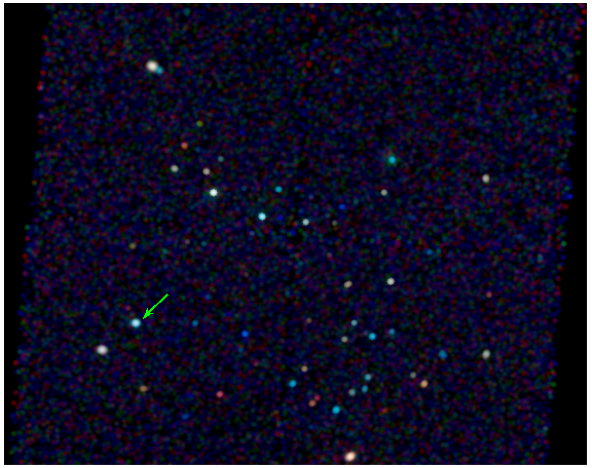
This new suite of scripts makes analysis quicker

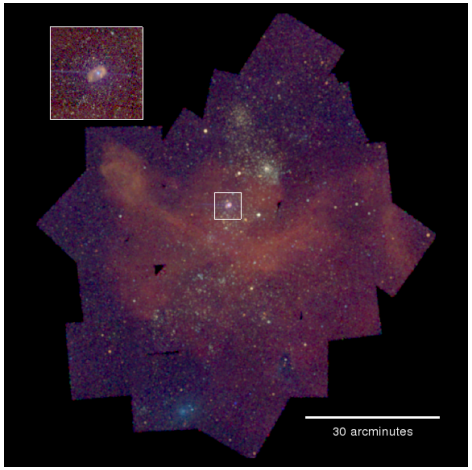




one script

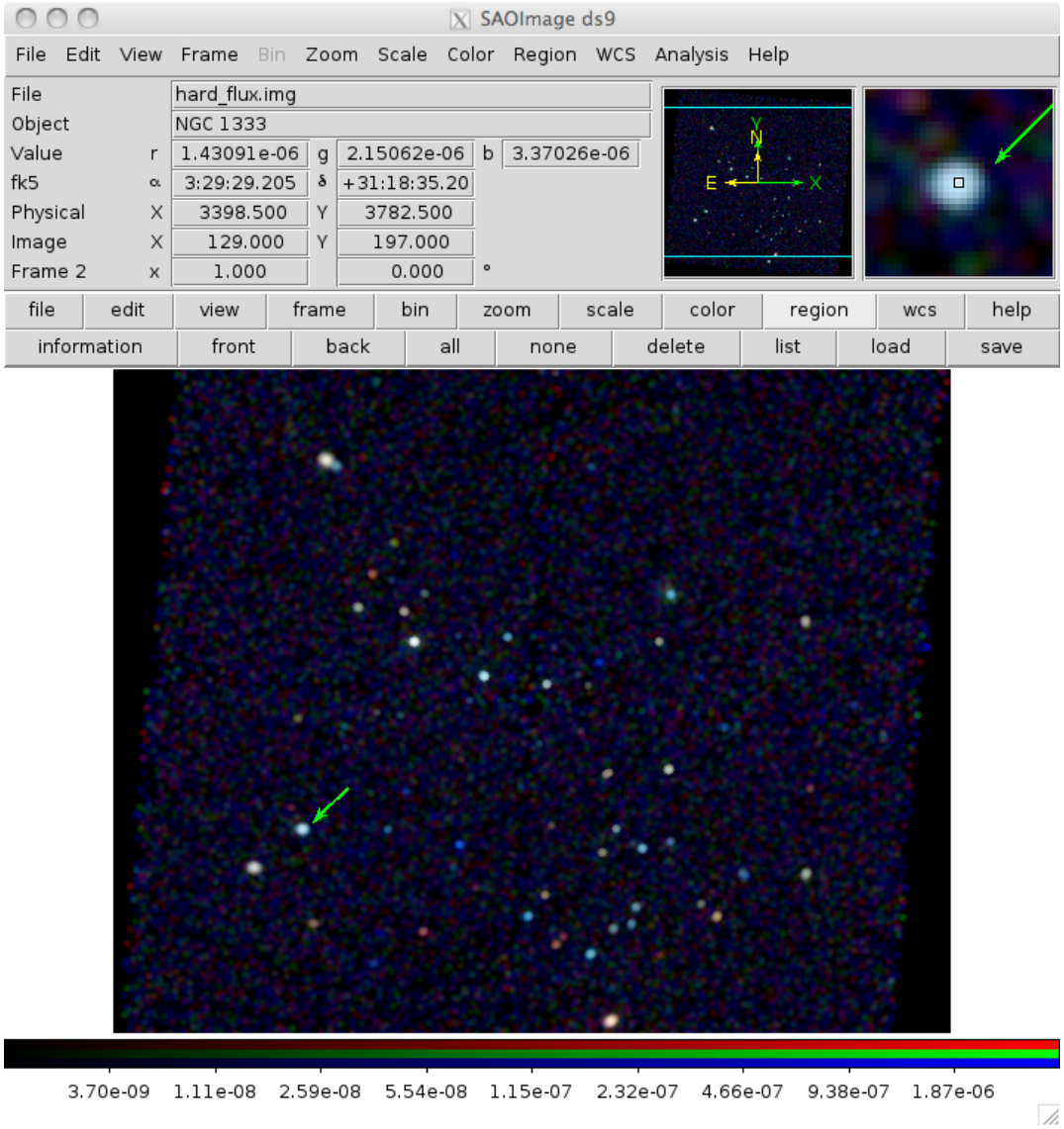
Two examples: srcflux and merge_obs





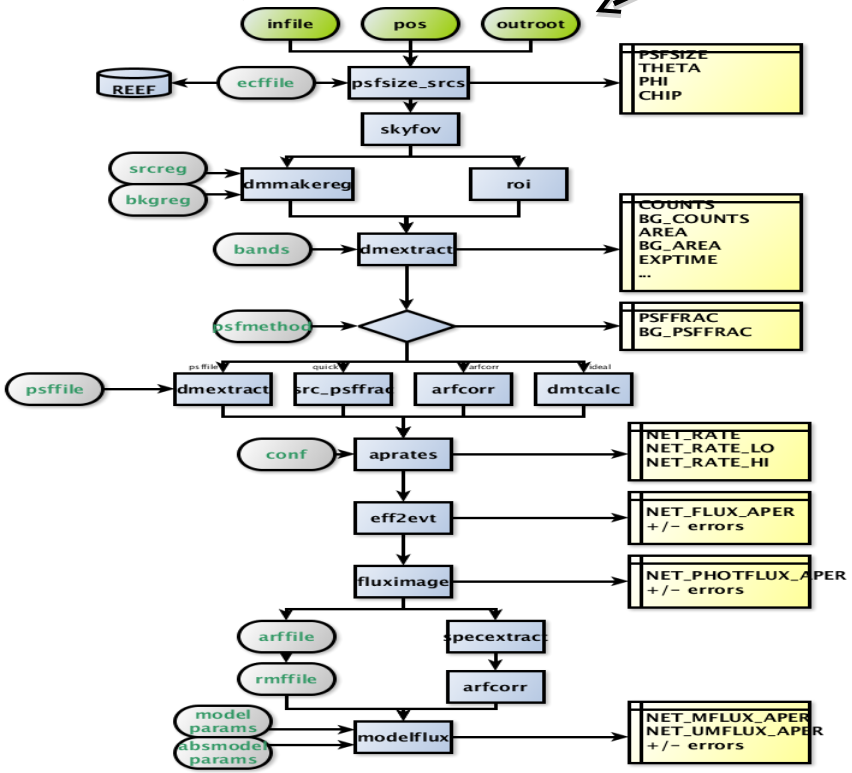
Calculating Source Flux

What is the X-ray flux of this source?



Calculating Source Flux

$ **srcflux** myevt2.fits "03:29:29.250 +31:18:34.73" myflux



Encodes the logic described in six different CIAO threads.

Return count rates and fluxes and errors with all appropriate corrections.

Uses many tools written for the Chandra Source Catalog.

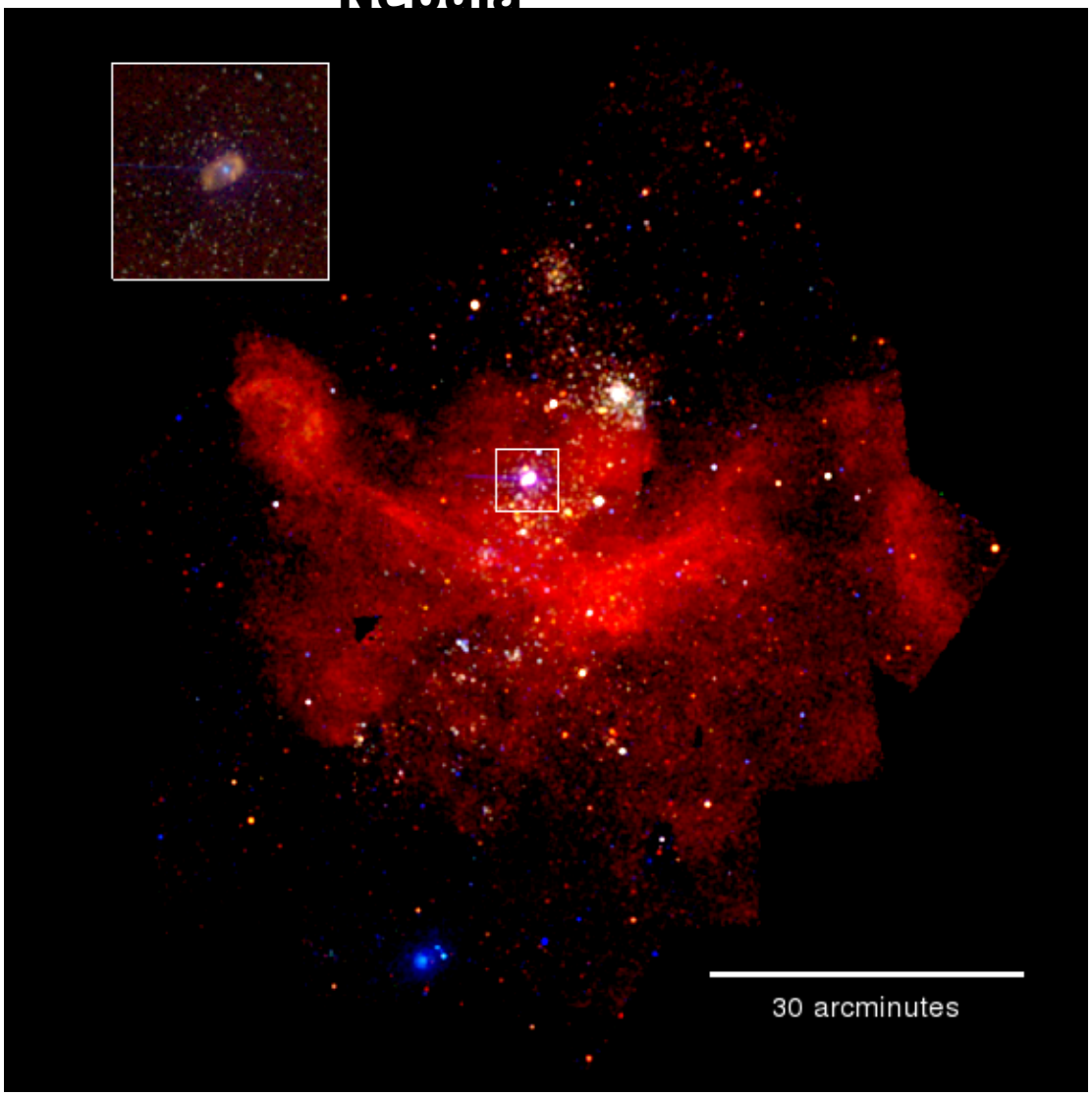
Complementary to it for special cases and fields not covered by the catalog.

Summary of source fluxes

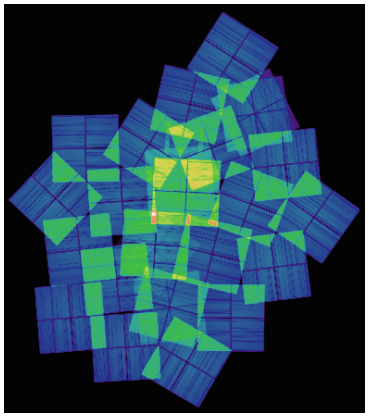
Position	0.5 - 7.0 keV
	Value 90% Conf Interval
3 29 29.25 +31 18 34.7	Rate 0.0398 c/s (0.0381,0.0415)
	Flux 5.17E-13 erg/cm2/s (4.94E-13,5.39E-13)
	Mod.Flux 4.38E-13 erg/cm2/s (4.2E-13,4.57E-13)

Merging Observations

Eta Carinae Nebula



Three-color image of 41 combined ACIS-I observations (0.5-7 keV)



Produced with four “simple” commands

1.find and download the data

2.reprocess the observations

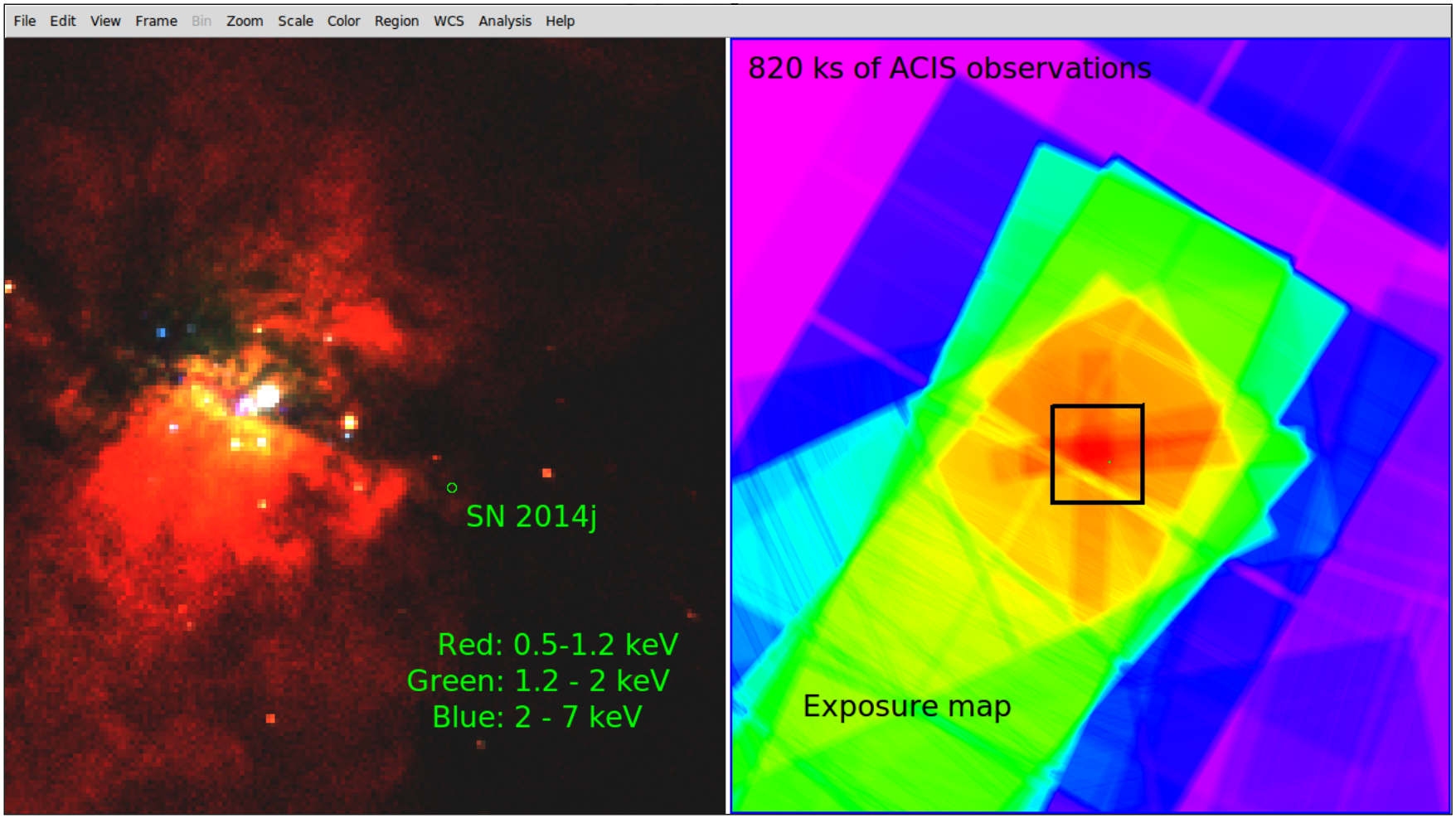
3.create the combined, exposure corrected images

%**merge_obs** “*evt2.fits” combined_data

4.create the three-color image to display

Merging Observations

M82 - SN

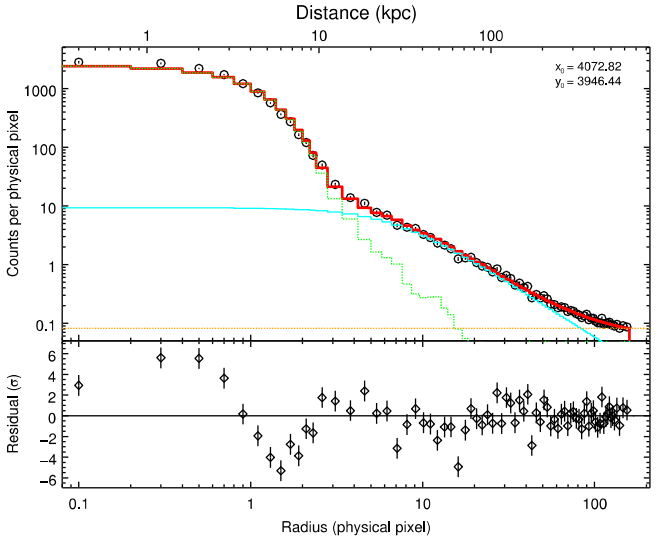


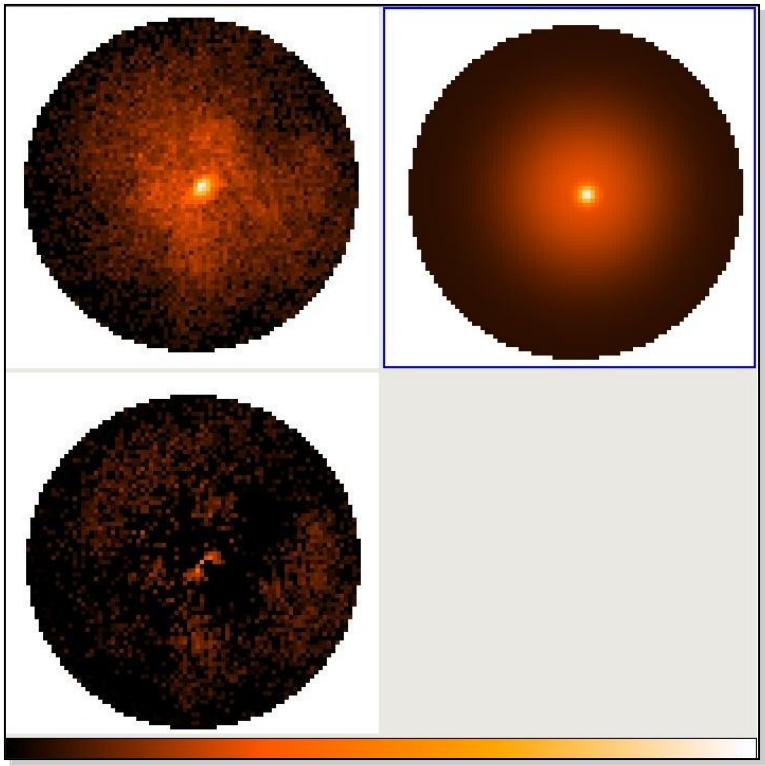
Combined 21 ACISobservations from 1999 to 2013
Created three color closeup image of central region
Allows setting upper limit to flux at SN location (ATel #5798)

Sherpa: Modeling and Fitting in Python

Sherpa

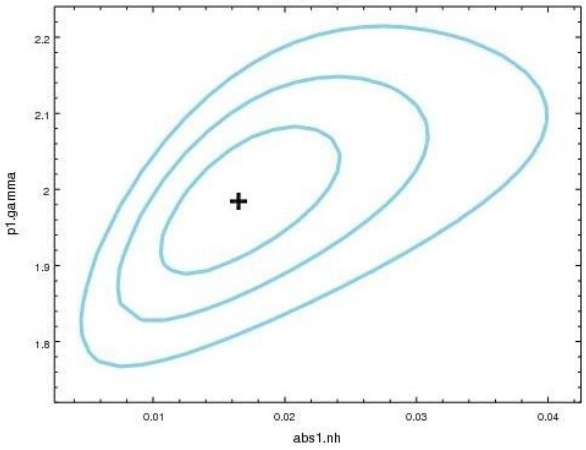
Modeling and fitting for 1-D and 2-D datasets **in any waveband** including: spectra, images, surface brightness profiles, light curves, general ASCII data.





Coded in a Python environment – familiar to the new generation of astronomers and used in other missions

Model Poisson and Gaussian data

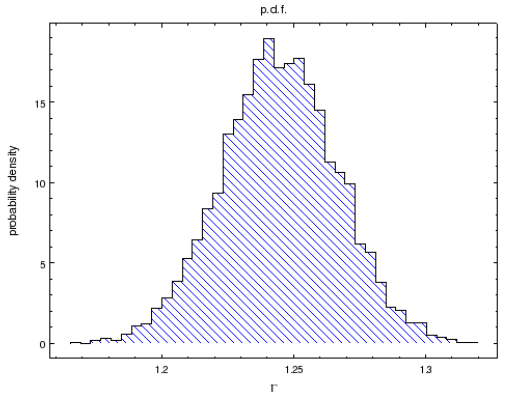


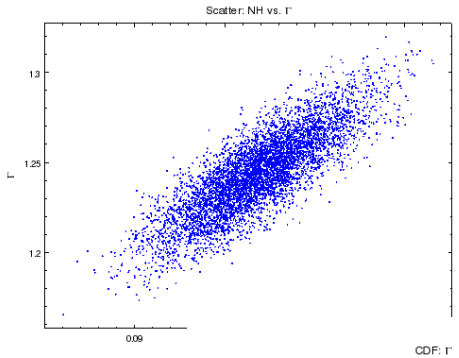
Calculate confidence levels on the best-fit model parameters

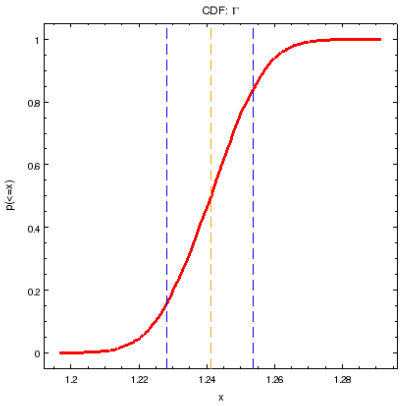
Sherpa: Modeling and Fitting in Python

Sherpa

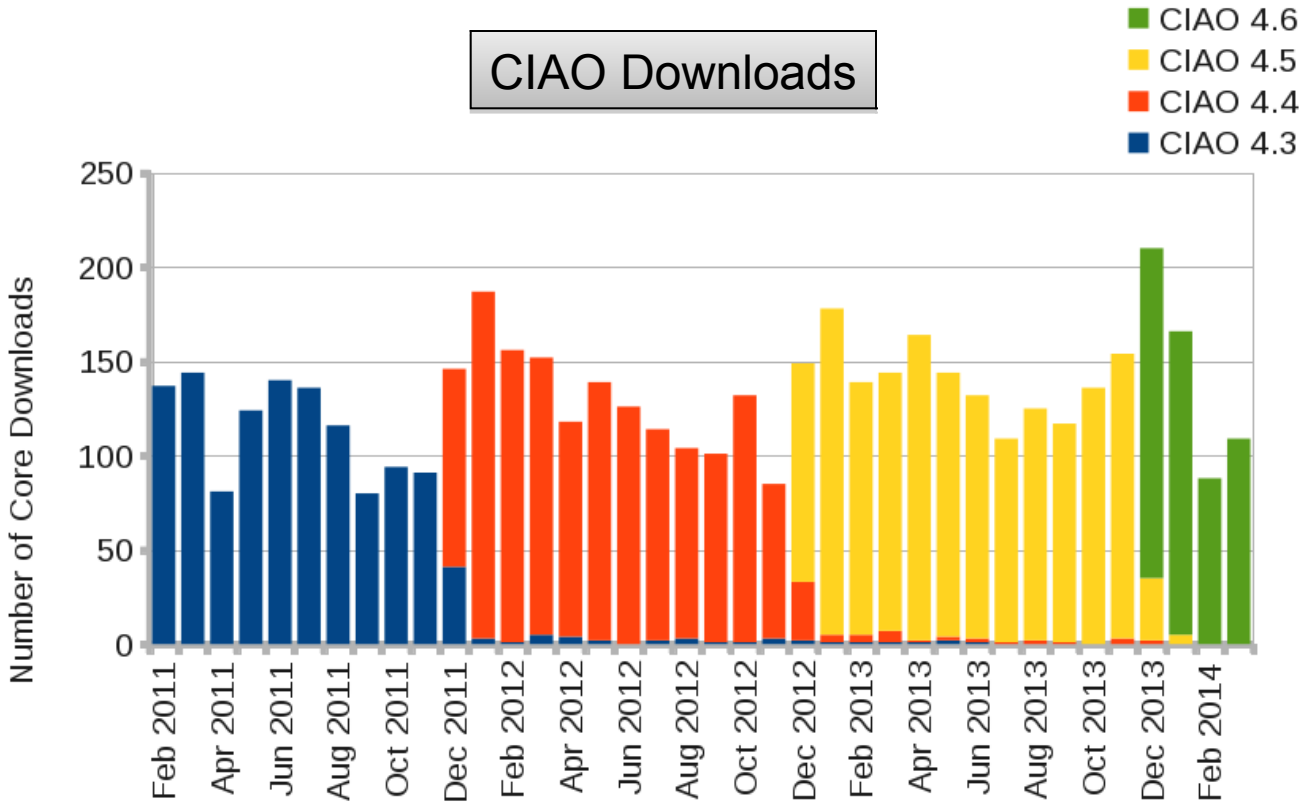
- comes with well-tested, robust optimization methods - e.g. Levenberg-Marquardt, Nelder-Mead Simplex or Monte Carlo/Differential Evolution
- comes with statistics for modeling Poisson or Gaussian data
- can perform Bayesian analysis with Poisson Likelihood and priors, using Metropolis or Metropolis-Hastings algorithm in the MCMC (Markov-Chain Monte Carlo); allows to include non-linear systematic errors (calibration uncertainties) in the analysis
- is extensible (with python and compiled code):
  - is used in CIAO tools and scripts
  - in the Xija Chandra thermal modeling code
  - is used in the TeV HESS data analysis software
  - is used in the IRIS spectral energy distribution program

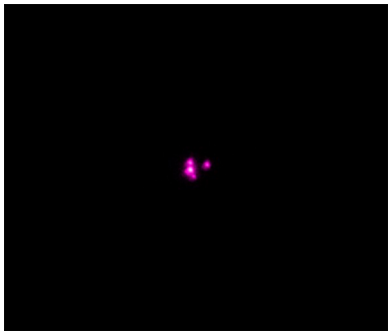


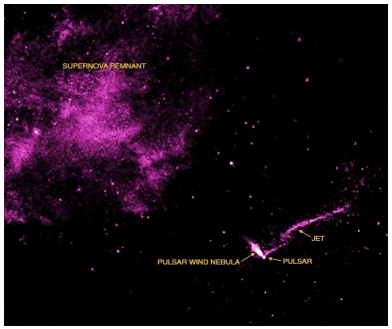


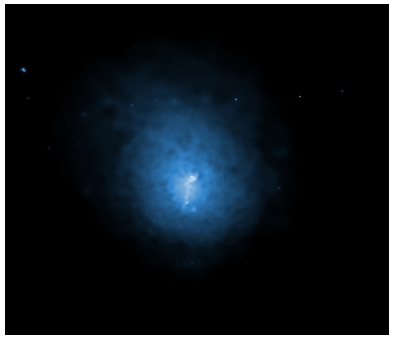


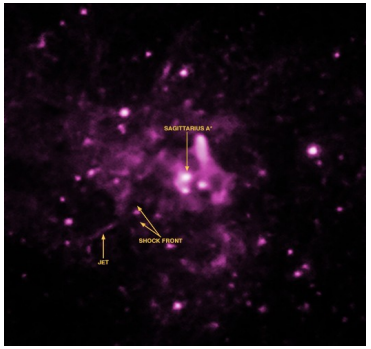
CIAO continues to support Chandra science

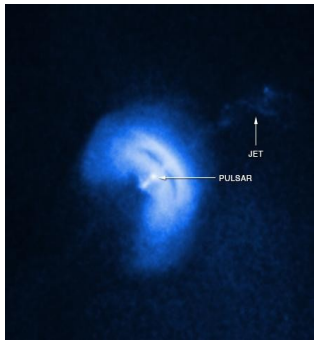












2013-14 Press Release Images