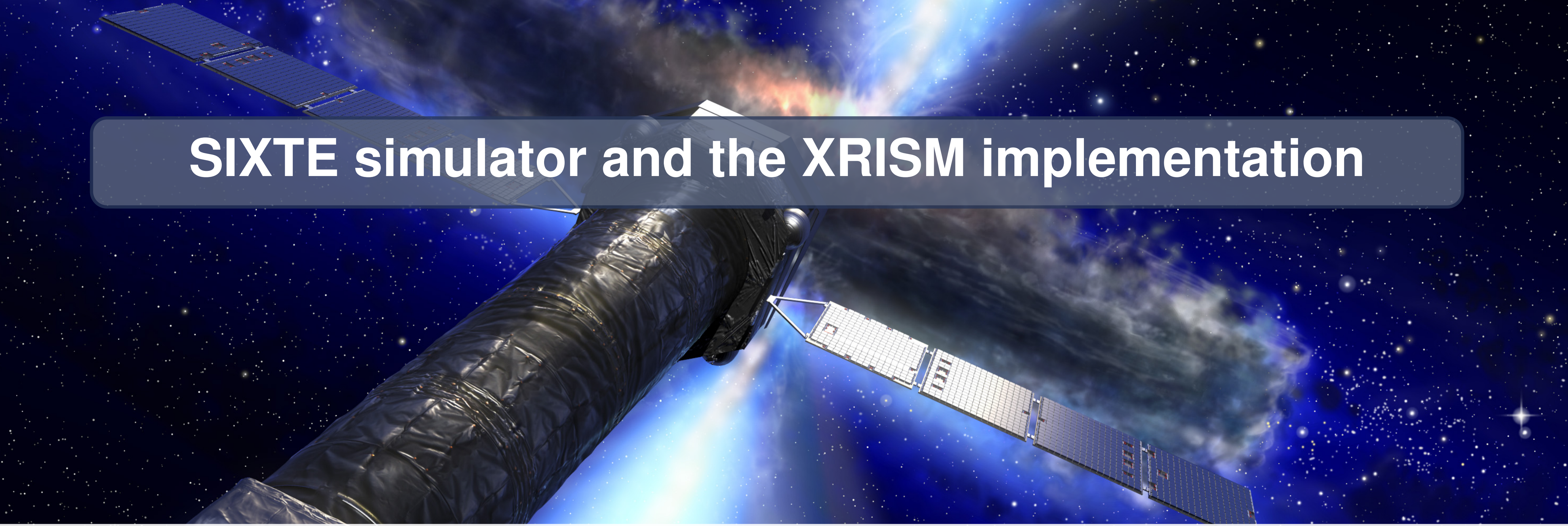
SIXTE simulator and the XRISM implementation



Thomas Dauser & Maximilian Lorenz on behalf of the SIXTE team

Remeis Observatory & ECAP

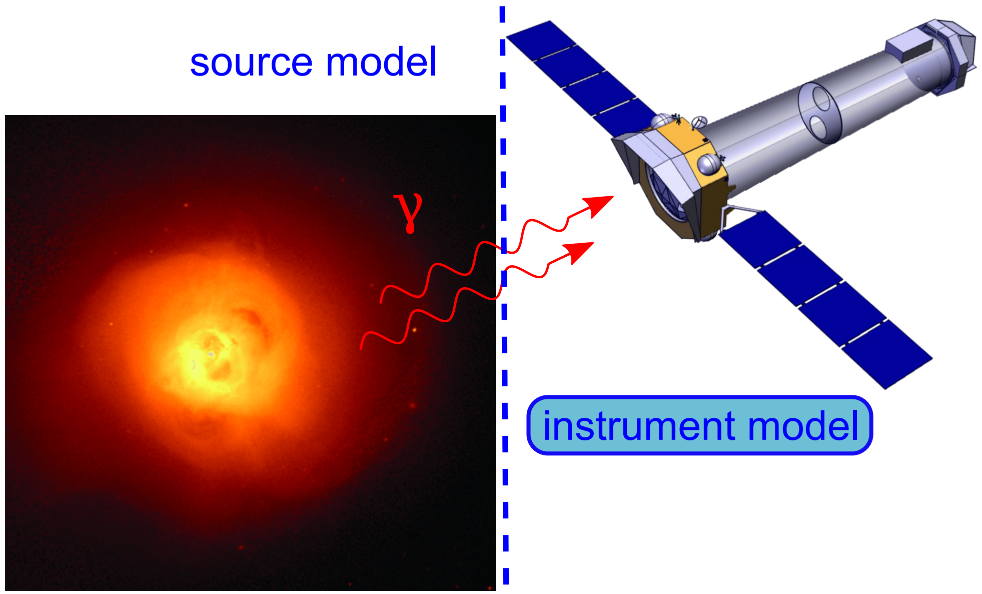
L. Dauner, C. Kirsch, O. König, D. Lochner, N. Reinmann, J. Wilms (ECAP),
E. Cucchetti, P. Peille (CNES), M. Ceballos, B. Cobo (IFCA), and many others

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

1st XRISM science performance and data analysis workshop, Geneva, 2024-02-12

SIXTE Introduction

SIXTE Overview



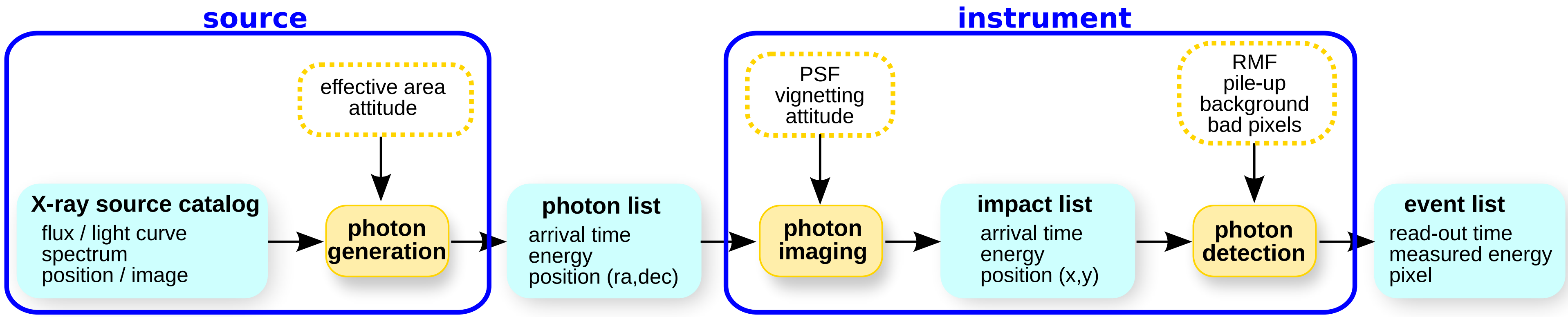
SImulation of X-ray TElescopes

SIXTE simulates the full detection chain from the astrophysical source through imaging and detection.

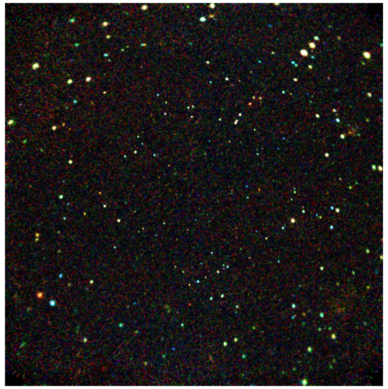
The simulation output are standard FITS files.

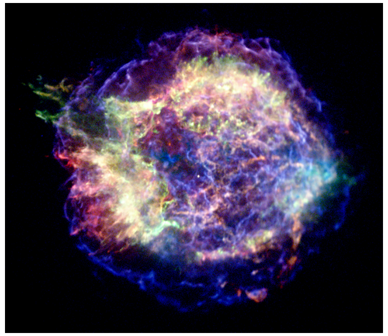
Tools for image creations, spectral extraction, exposure maps and ARF generation are provided as part of SIXTE.

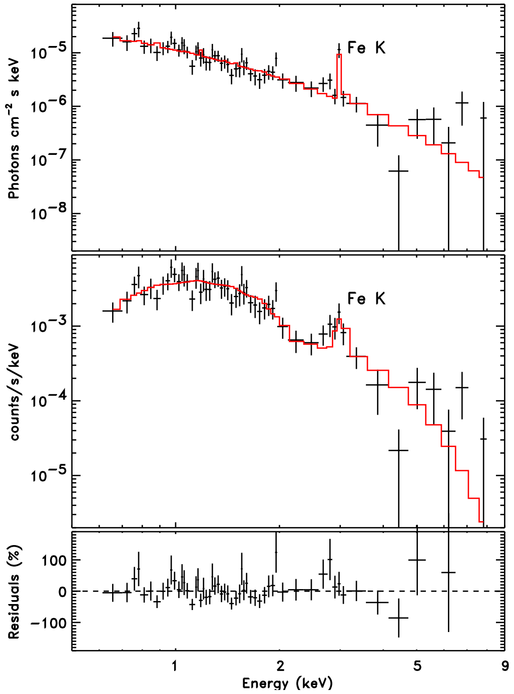
Note: Source and instrument models are separate. Source definitions can be re-used for any instrument!

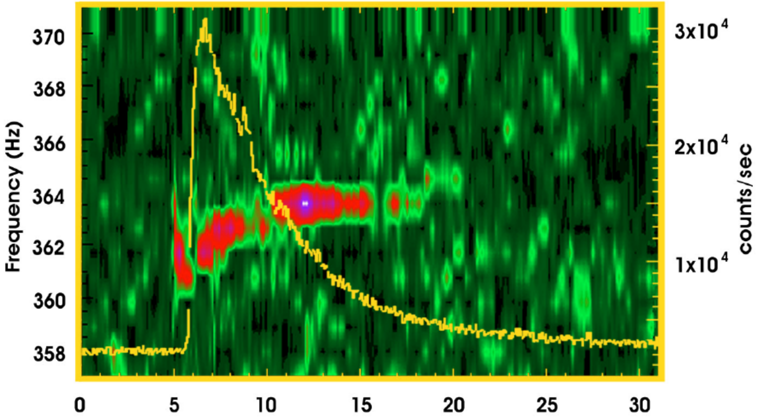


SIMPUT Format









Sources are characterized by:

- position: (α, δ)
- spectral shape: $F(E)$
- flux distribution: $F(\alpha, \delta, E)$
- variability: $F(\alpha, \delta, t, E)$
- foreground absorption: $N_{\mathrm{H}}(\alpha, \delta)$

Features:

- try to be as close as possible to reality, no artificial limitations on source spectral shape, images, etc.
- make catalogs of SIMPUTs, scales up to millions of sources by reusing spectra
- compatible w/other simulators (`simx`, `MARX`)

Detector Modelling

Detector Models

Detector modelling in SIXTE tries to achieve a balance: Sufficient detail to be representative, but still able to run long simulations on Laptop-like resources

SIXTE is already used for many missions, such as *eROSITA*, *Athena* X-IFU and WFI, most NASA X-Ray probe mission concepts, . . .

Based on this heritage, we have models to simulate *XRISM*:

Resolve

Microcalorimeter model with grading and crosstalk (and PSP limits in process)

Xtend

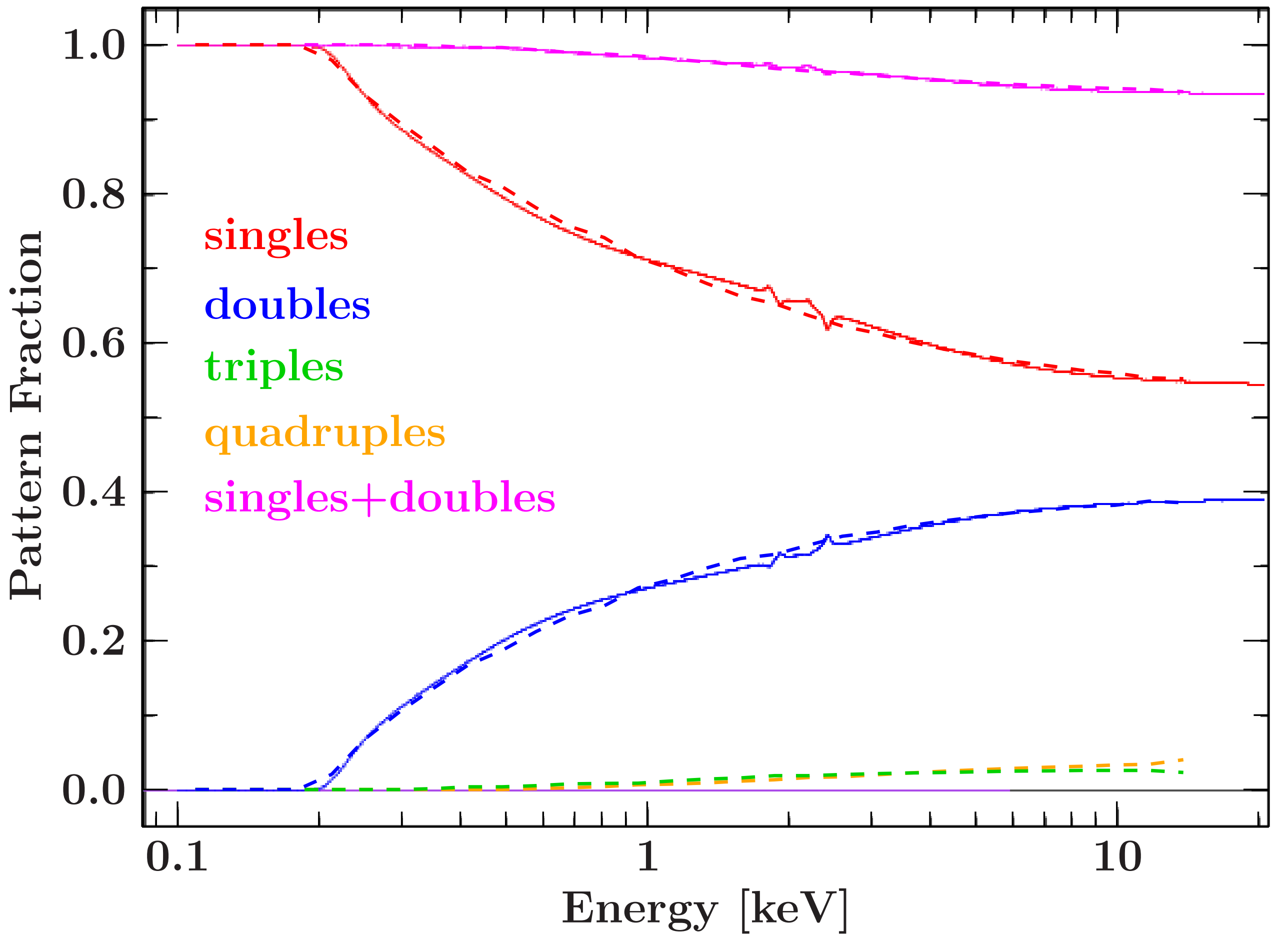
CCD model with multiple detectors and readout modes

CCD Effects – Patterns and Pileup

In CCD (or generally semiconductor) detectors, SIXTE models the spread of photon signals over multiple pixels via a charge cloud model.

Based on a photon's impact position and energy, a frame contains different event patterns.

Example:
Reconstruction of pattern fractions in EPIC pn on *XMM Newton* (solid lines) with SIXTE (dashed lines)



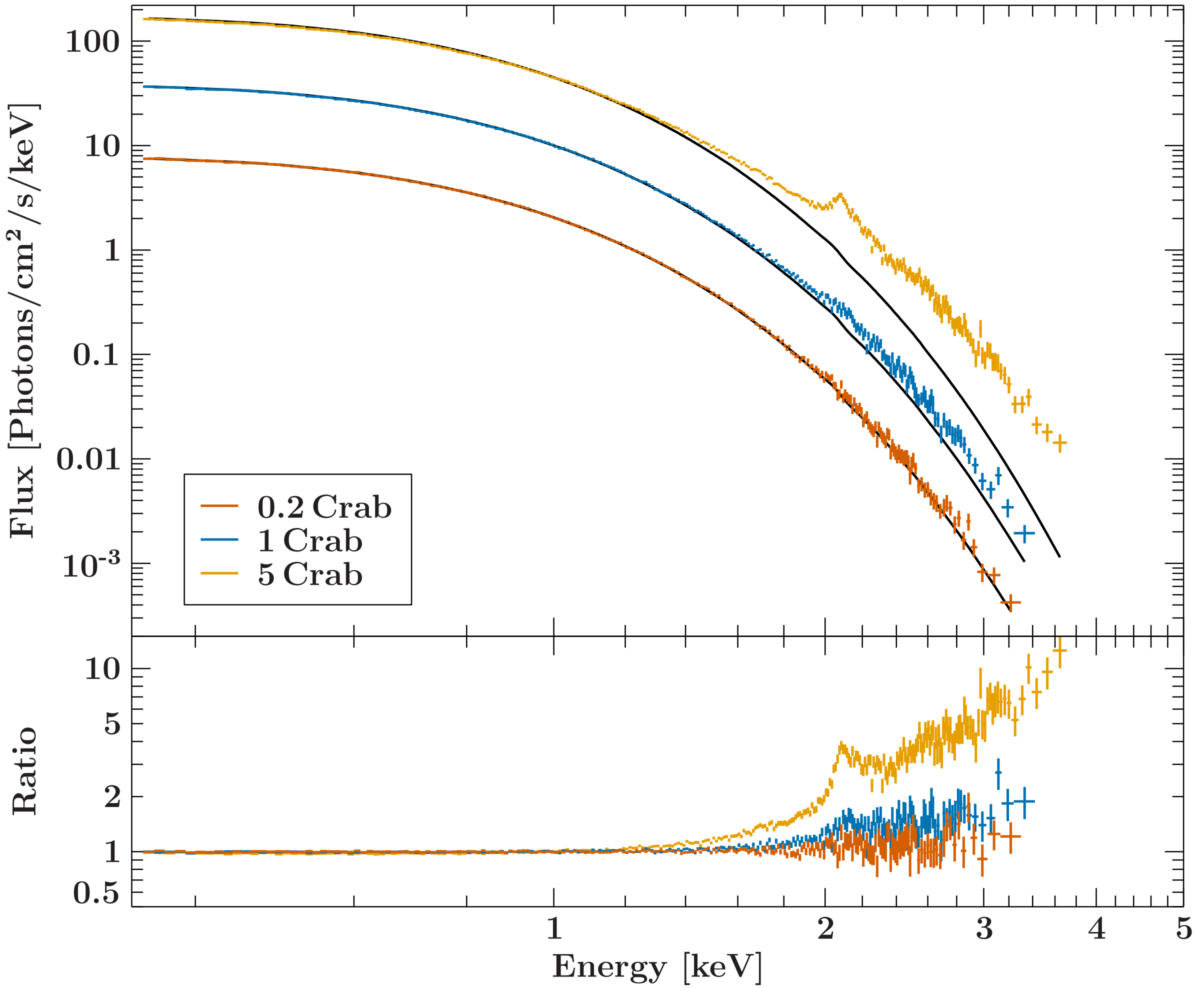
Dauser et al. (2019)

CCD Effects – Patterns and Pileup

In CCD (or generally semiconductor) detectors, SIXTE models the spread of photon signals over multiple pixels via a charge cloud model.

At high count rates, multiple photons may hit the same pixel within the same frame, or form a fake, valid looking pattern. This is called pileup and leads to a distortion of the spectrum.

Example: *Athena* WFI fast detector simulation of a 200 eV black-body at various fluxes. At high flux, the spectral shape (black, solid) is distorted.



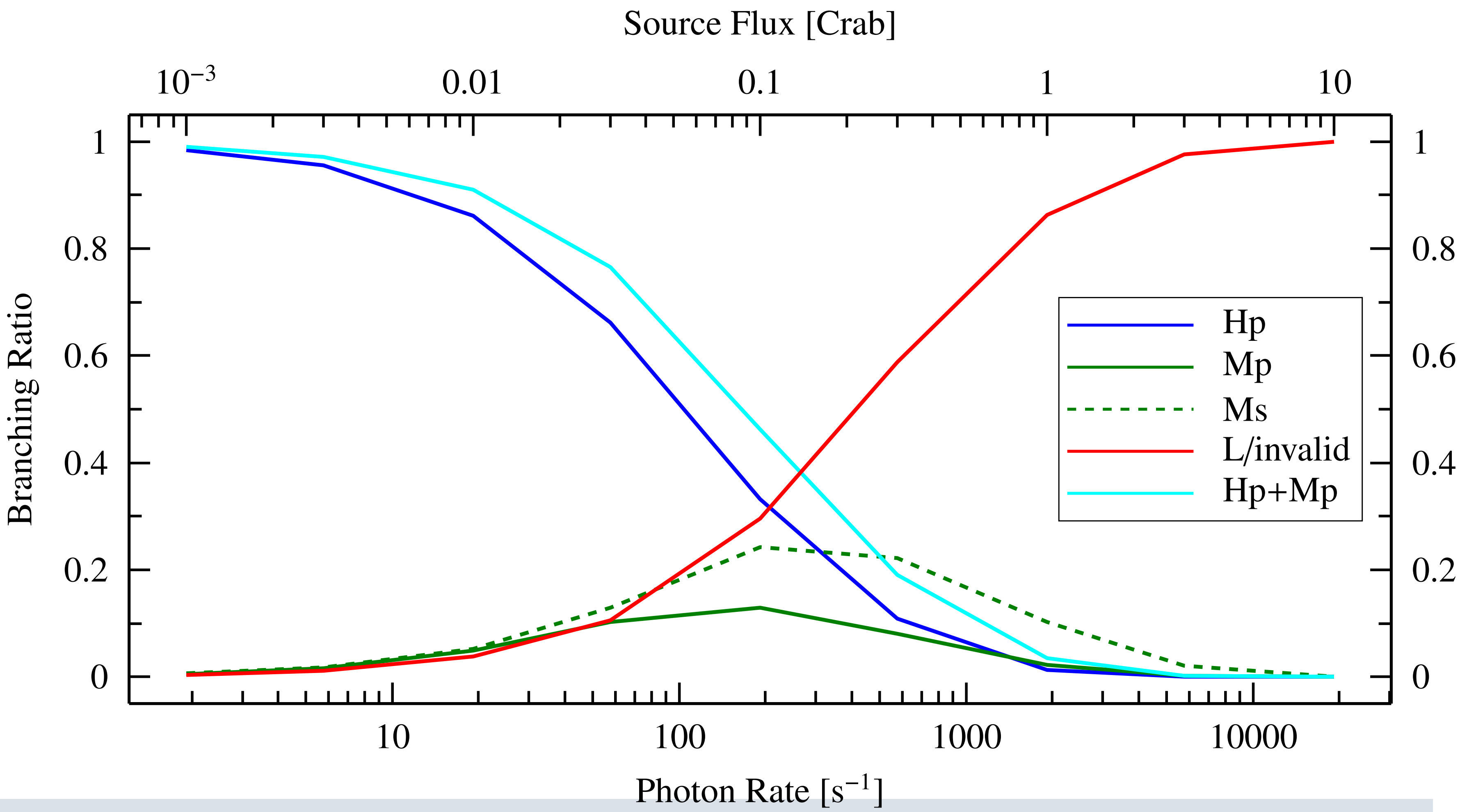
Dauser et al. (2019)

Microcalorimeter Effects – Grading

For microcalorimeters, SIXTE implements grading, i.e. varying energy resolution as a function of pulse separation. This is automatically included in every simulation.
Here, we supply a list of `post` and `pre` pulse distances and an RMF for every grade.

Example:
Reconstructed branching ratio plot for Resolve using SIXTE.

(Simulated Crab-like pointsource at different fluxes)

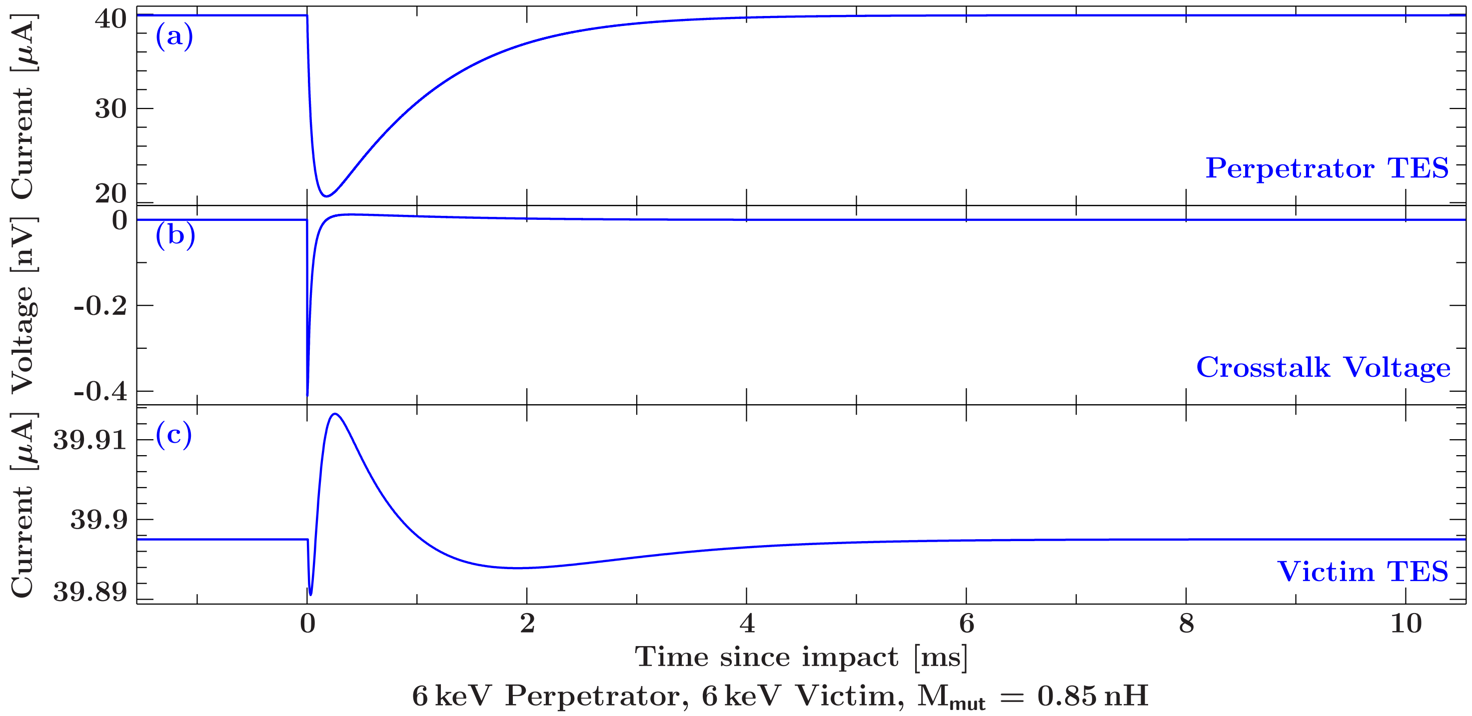


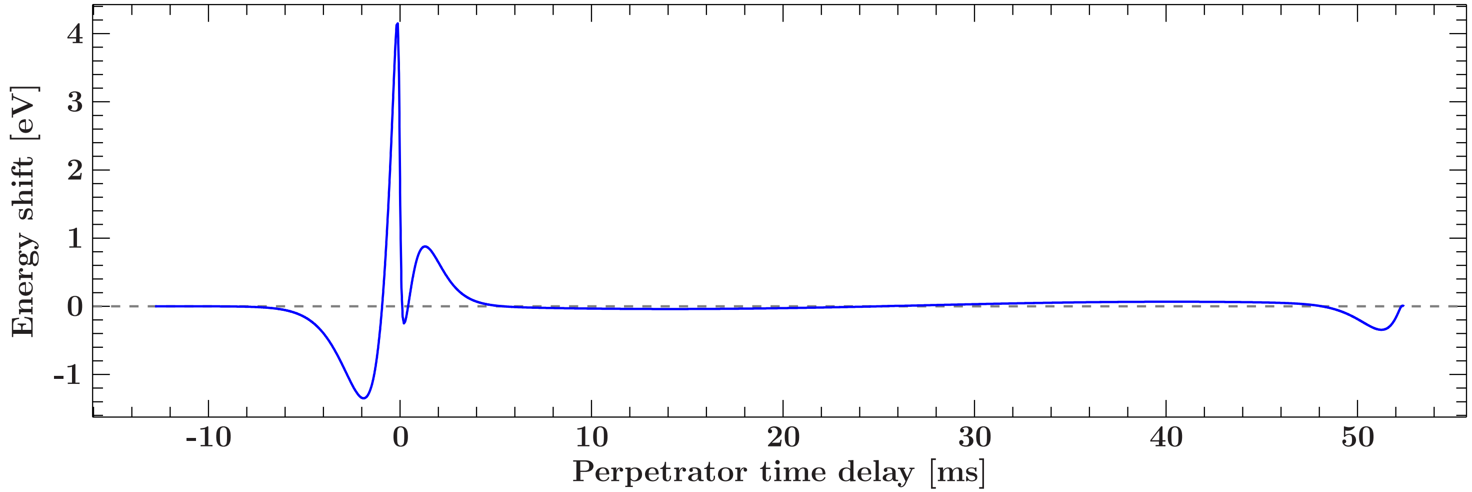
Microcalorimeter Effects – Crosstalk

Due to coupling between pixels (on focal plane or in readout), microcalorimeters can experience crosstalk.

This is significant for high count rate observations, with photons hitting coupled pixels during each other's "record" intervals.

Right Example: Electrical crosstalk in X-IFU via mutual inductance. Used `xifusim` simulations to characterize effect (top) and generate lookup table (energy shift vs time, bottom).



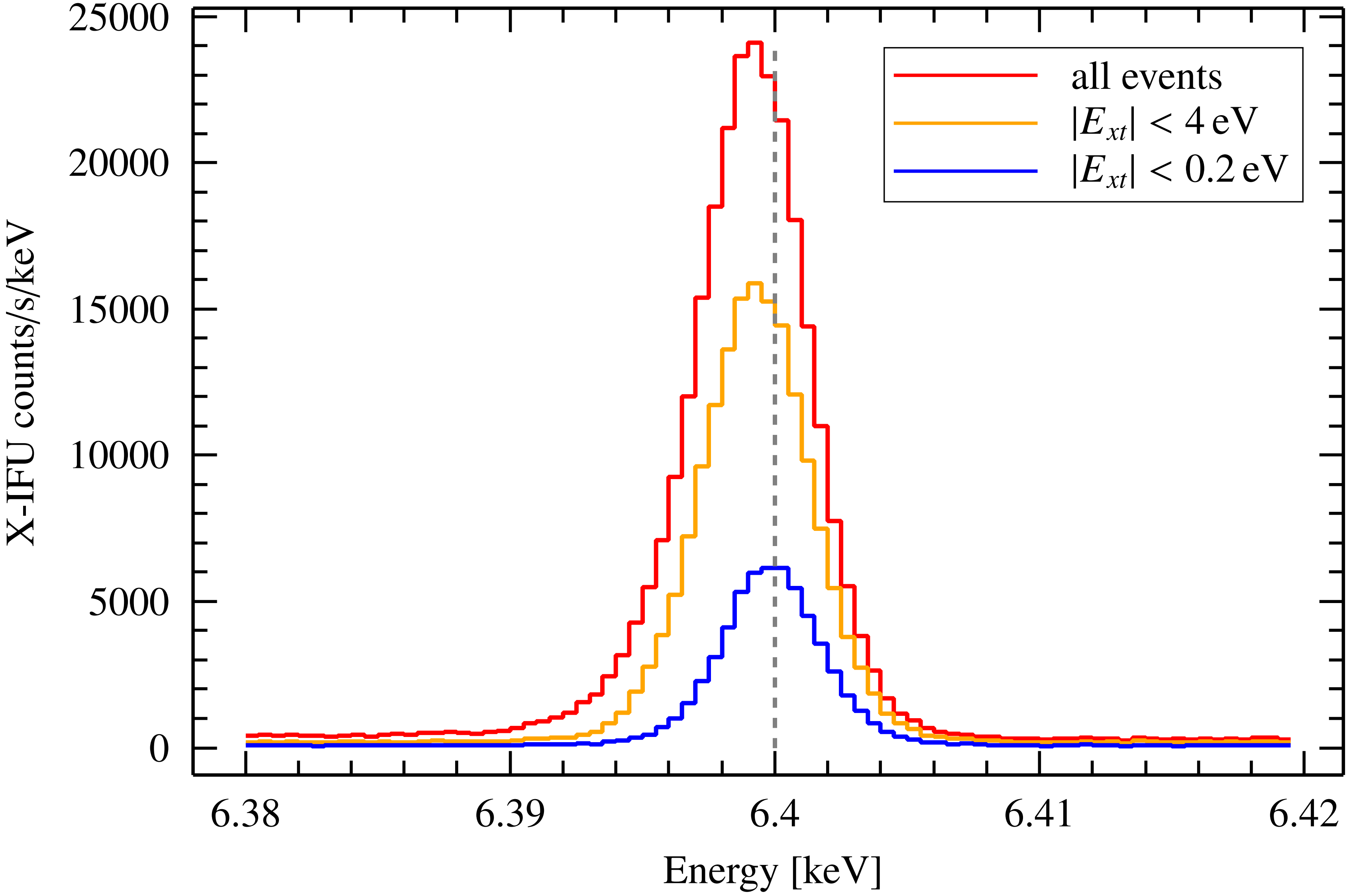


Microcalorimeter Effects – Crosstalk

SIXTE can use lookup tables to calculate crosstalk during simulations.

Right example: Gaussian emission line on top of Crab-like continuum. The line is shifted and distorted by crosstalk.

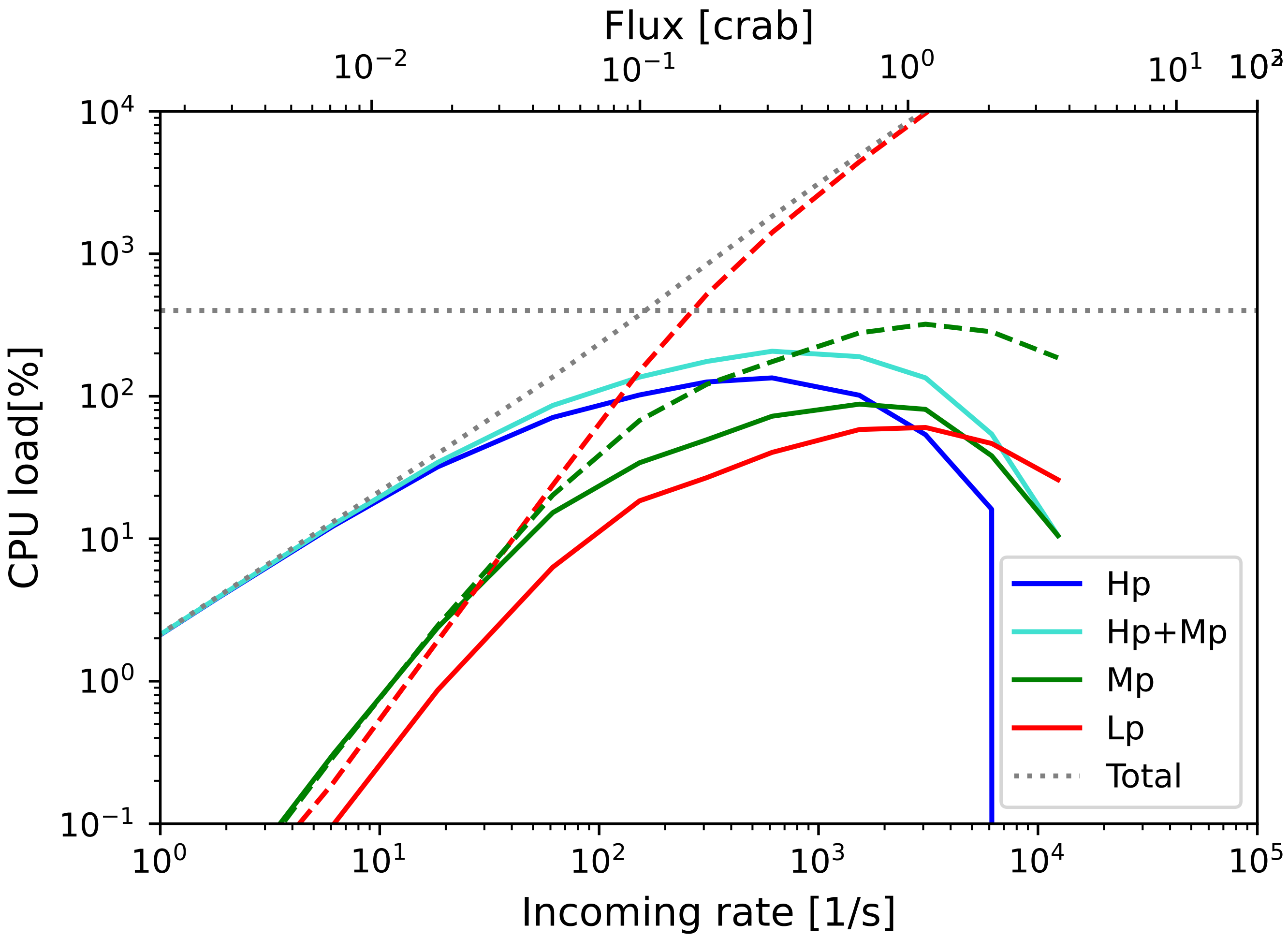
As crosstalk is predictable, users can filter out affected events. This restores the line shape, at a cost of throughput.



Microcalorimeter Effects – CPU Limits

Currently work in progress, BSc thesis of David Lochner

- Event processing in *Resolve* is handled by four CPUs, one per quadrant
- Events are stored in FIFOs before processing. If the event rate per pixel is higher than the processing rate, FIFOs can overflow, leading to loss of events
- Currently trying to model this effect to implement it in SIXTE



Running SIXTE

SIXTE Resources

First, check the SIXTE webpage:

`https://www.sternwarte.uni-erlangen.de/sixte/`

- Documentation: 95p. manual and Dauser et al. (2019, A&A 630, 66)
- Help Desk: `sixte-support@lists.fau.de` – When in doubt, ask questions here
- Previous SIXTE workshops: videos, slides and tutorial materials
- Source Code: tarballs on webpage, or GitHub
- Useful SIMPUTS: Background AGN lists, ROSAT All-Sky Survey Catalogs and Soft X-ray Background, …

Installation: SIXTE can run locally on Linux and MacOS, and is also available on the JHU SciServer (via the `sixte_users` group). For either case, see

`https://www.sternwarte.uni-erlangen.de/sixte/installation/`

SIXTE Workflow

(1) Preparation of the simulation input

- Mostly use tool `simputfile`
- May also use tools for more complex source geometries (`simputmultispec`) or merge multiple source catalogs (`simputmerge`)
- SIMPUT files are FITS files and can also be manually written

(2) Running the simulation

- Use tool `runsixt` or detector specific tools
- Output: one or multiple standard FITS event files

(3) Analyzing the simulation

- Tool `makespec`: Extract spectra
- Tool `imgev`: Create images
- Tool `makelc`: Create light curves
- Also includes tools for exposure maps, ARF generation, ...
- Data products are compatible with common X-ray data analysis software

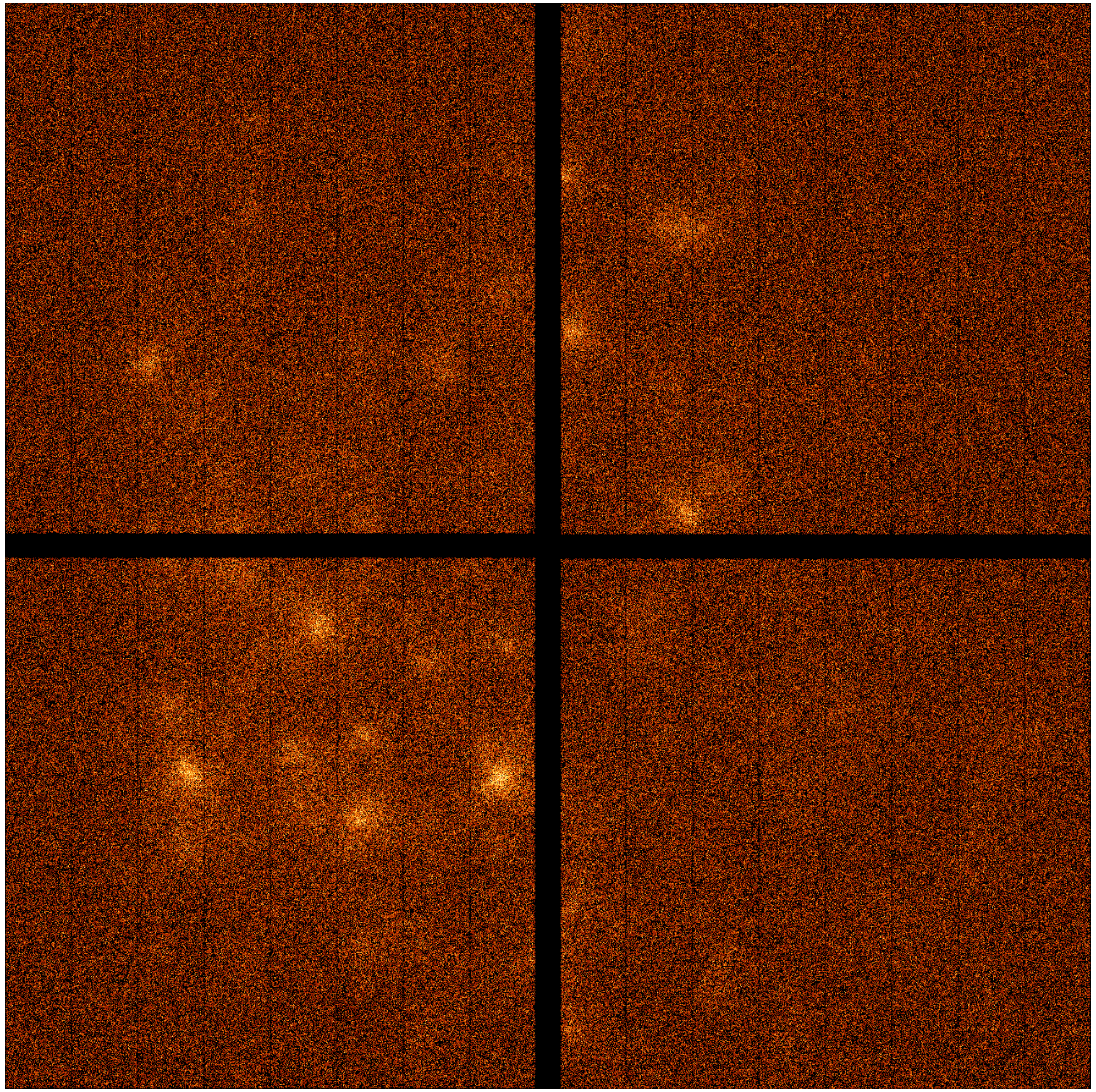
Example Simulations

Simulation Example – Survey

Simulate the Chandra Deep Field South with Xtend:

Overall 762 point sources and 50 clusters, with one spectrum per source type.

A 1 Ms simulation took $\sim$5 minutes to run.



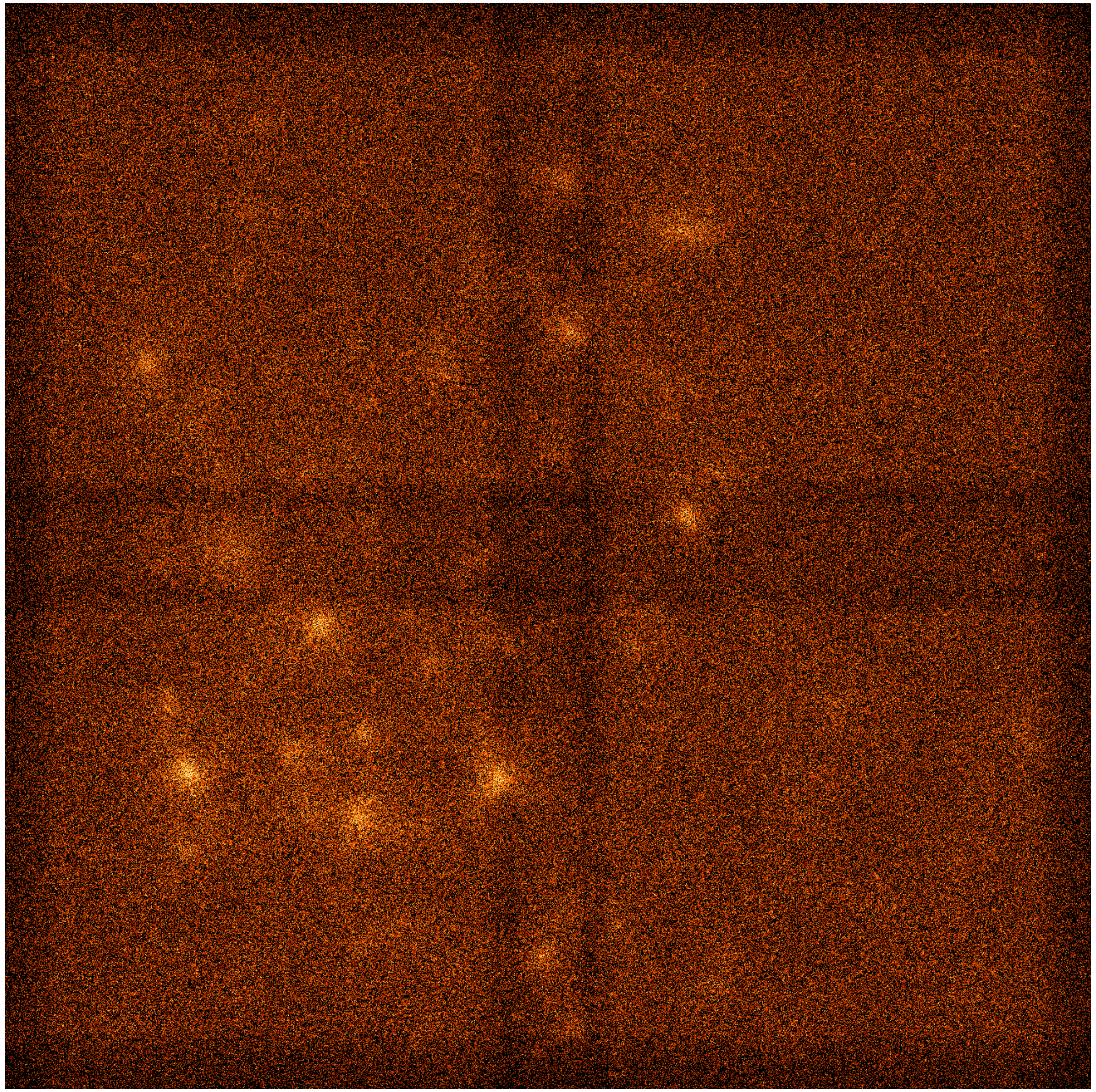
Simulation Example – Survey

Simulate the Chandra Deep Field South with Xtend:

Overall 762 point sources and 50 clusters, with one spectrum per source type.

A 1 Ms simulation took ∼5 minutes to run.

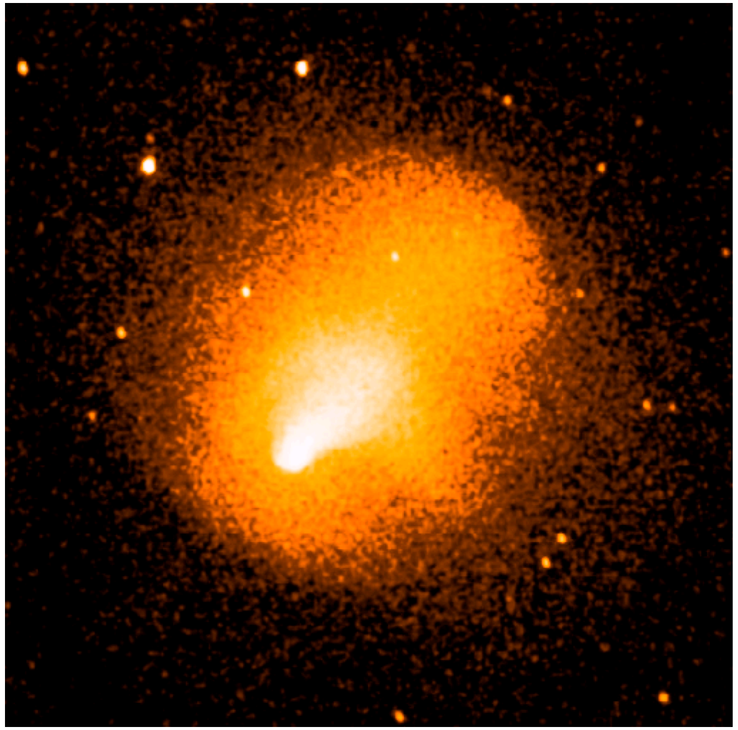
SIXTE also supports attitude files. Fix chip gaps by dithering.

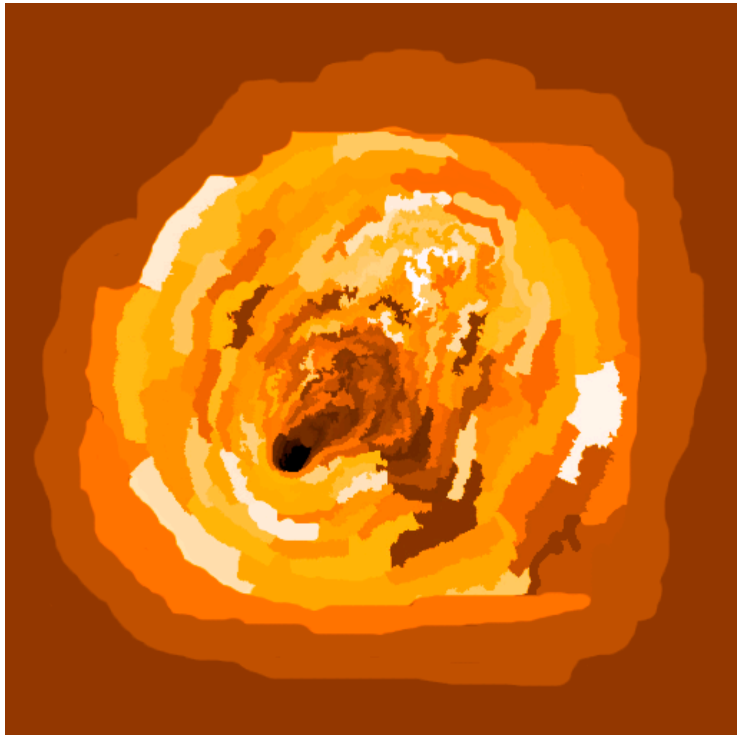


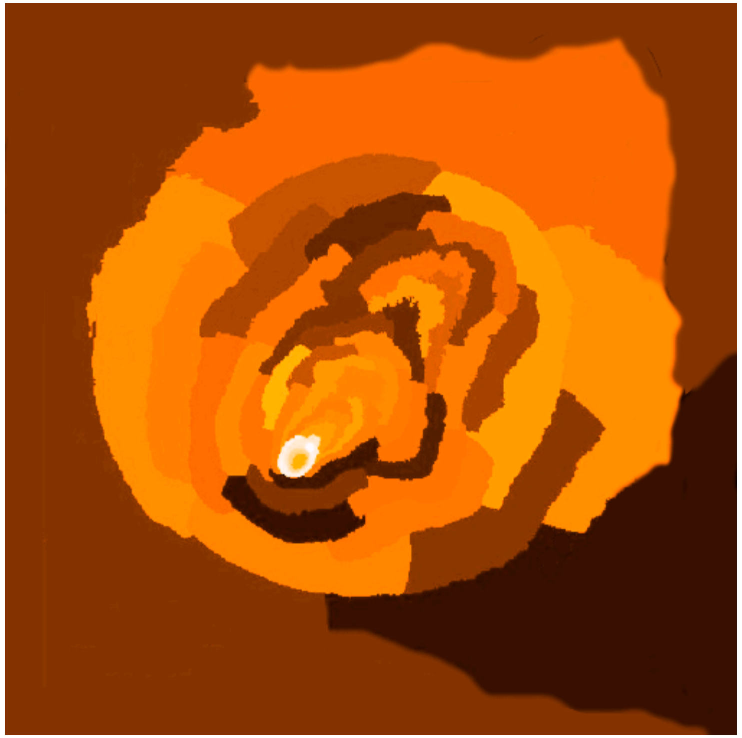
Simulation Example – Galaxy Cluster

For extended sources, SIXTE provides the tool `simputmultispec`, which takes flux and parameter maps to build a spatially variable source.

Example: Luminosity and parameter (temperature, abundances) maps of Abell 2146 obtained by Russel et al. (2012) with *Chandra*

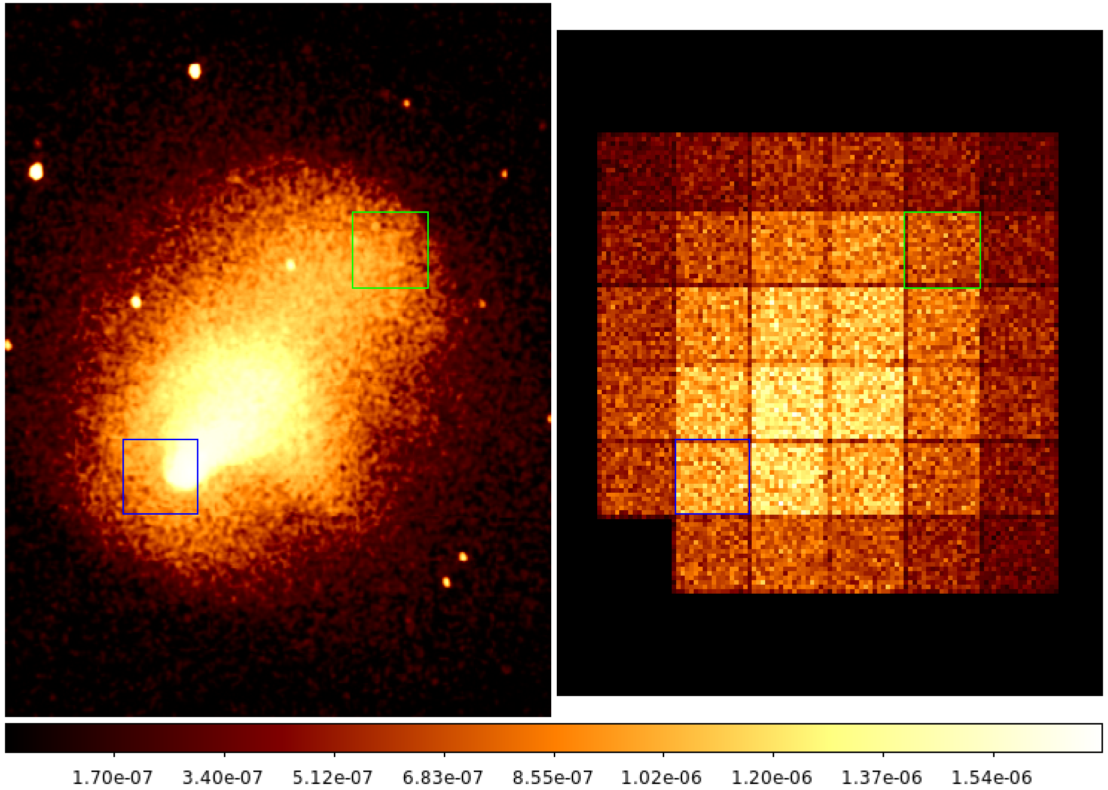


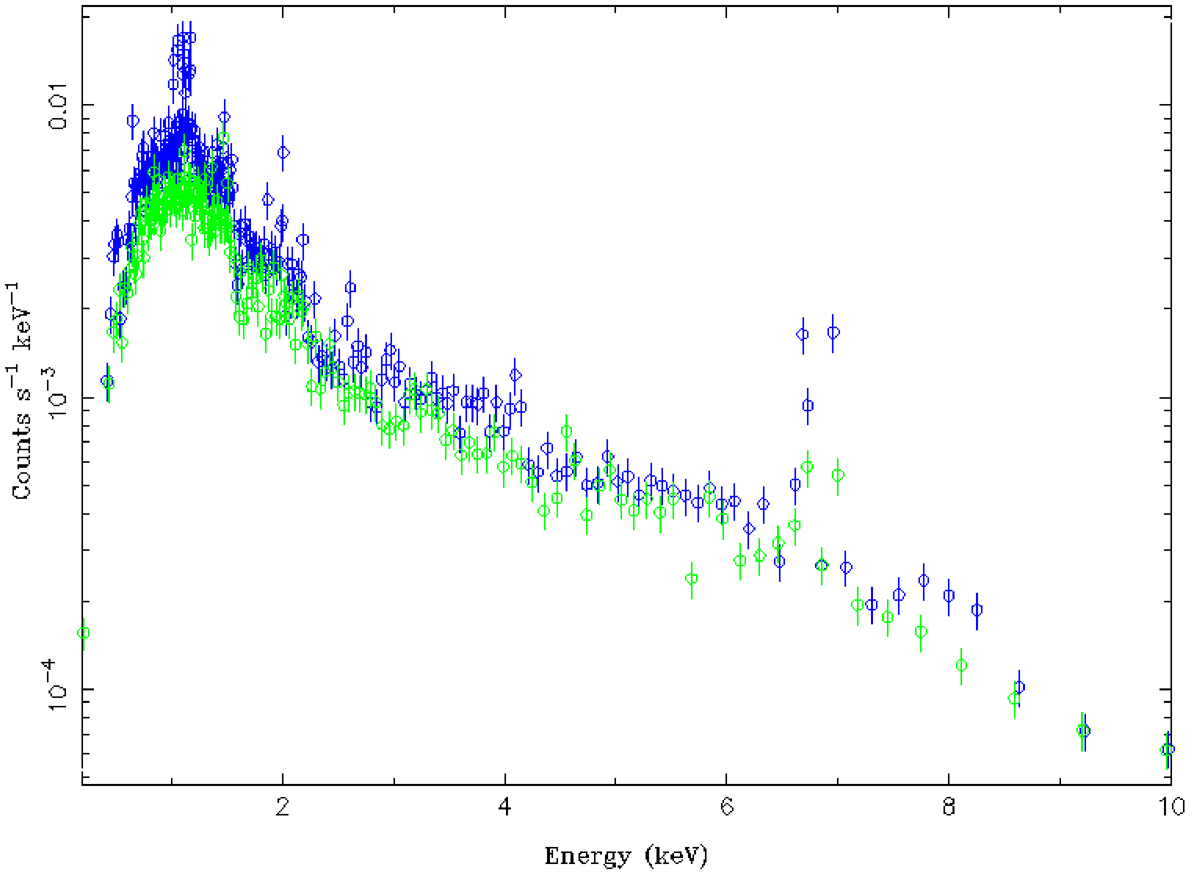




Simulation Example – Galaxy Cluster

Simulate 1 Ms with Resolve for this source (runtime: 70 seconds).
We can then extract single pixel spectra and compare them:





Simulation Example – Cas A

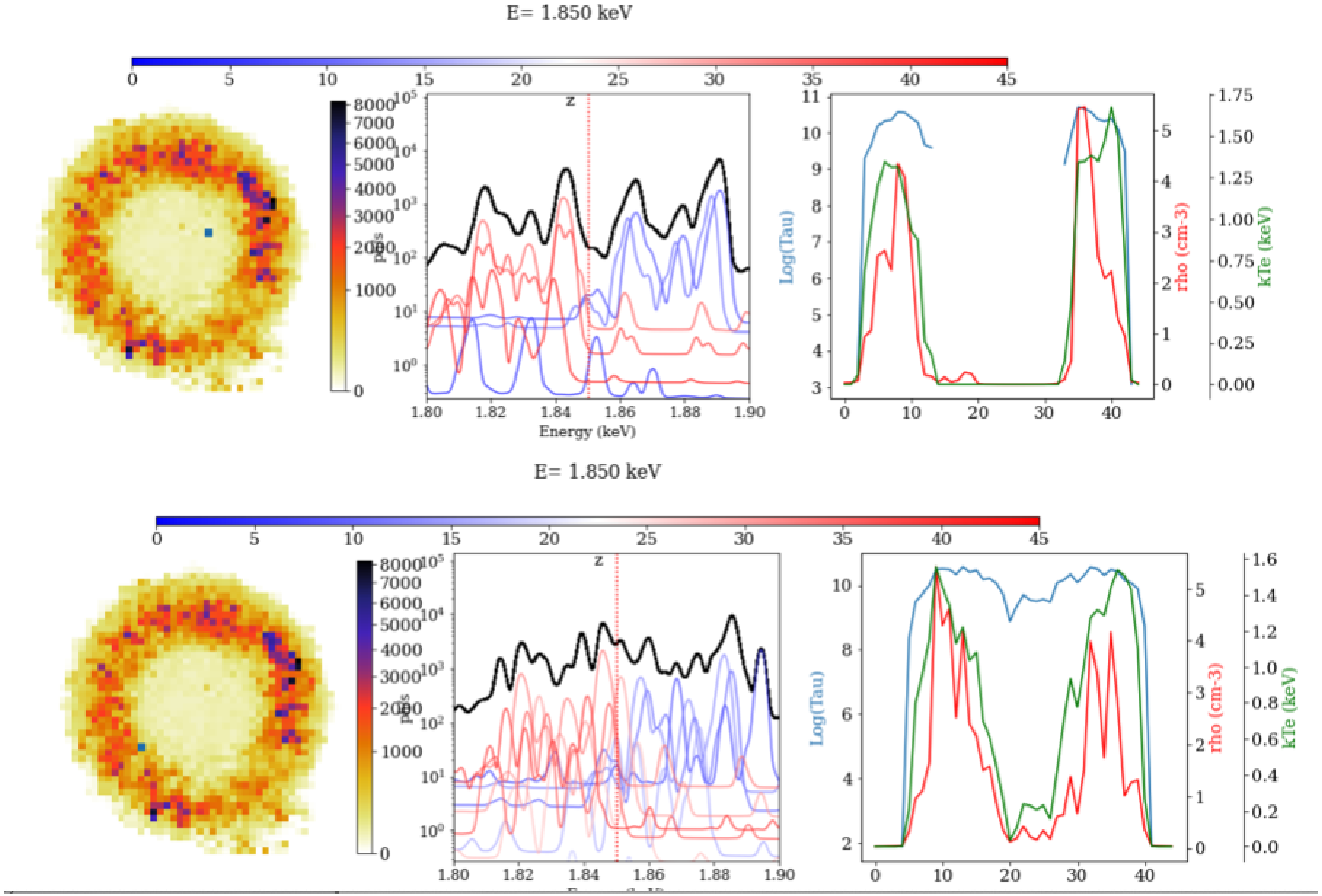
Extreme example: Use 3D simulations of extended sources (with help from Fabio Acero, CEA)

Here: Use Cas A simulation of Orlando et al. (2016) as input.

Subdivide into 191^3 voxels (depth included) and generate spectra, then sum up spectra along line of sight

$\Longrightarrow$ 23381 individual spectra, 4.4 GB

Parameters vary strongly along line of sight, including redshift!

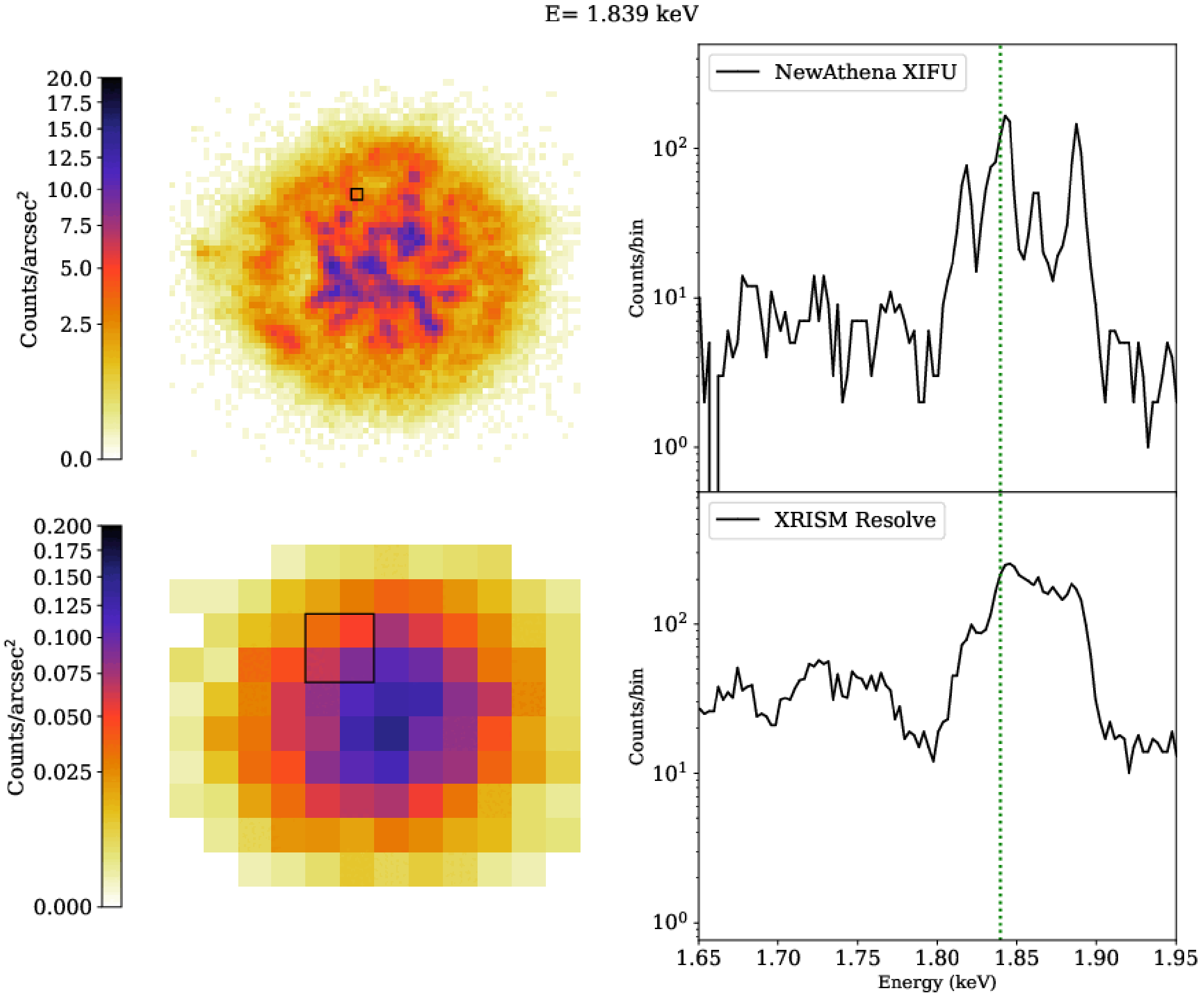


Simulation Example – Cas A

Extreme example: Use 3D simulations of extended sources (with help from Fabio Acero, CEA)

After simulation, make subimages scanning over Si-Line

$\Longrightarrow$ 3D tomography



Conclusions

When to use SIXTE

When not to use SIXTE

but `fakeit` or similar tools

- fainter point sources ($\lesssim$ 1 mCrab)
  $F_{0.5-2\mathrm{keV}} \lesssim 10^{-11} \mathrm{erg\,cm^{-2}\,s^{-}1}$,
  $F_{2-10\mathrm{keV}} \lesssim 2 \cdot 10^{-11} \mathrm{erg\,cm^{-2}\,s^{-}1}$,
  unless background starts to become important
- quick estimates

When to use SIXTE

and *not* `fakeit`

- bright sources ($\gtrsim$ 10 mCrab)
  i.e., many "famous" AGN, galactic sources
  here, high-count rate effects become relevant
- faint sources if background or exposure map matters
- imaging simulations
  e.g., galaxy clusters, AGN evolution, surveys
  - point source detection sensitivity
  - point sources in crowded fields
  - extended sources
- variability
  e.g., reveberation mapping, pulses, QPOs, . . .

When in doubt, you can also ask the SIXTE helpdesk

SIXTE Refactoring

Currently, SIXTE is undergoing an internal refactoring

- Cleanup of code base (SIXTE is >10 years old, with many contributors)
- General port from C to modern C++
- Unification of separate routines (e.g., microcalorimeter and CCD)
- Improvements to several tools (ARF generator, exposure maps)

Effect on end users will mostly be a single simulation executable `sixtesim`, replacing individual mission tools (`erosim`, `xifupipeline`, `athenawfisim`, ...)

Most other tools will have the same parameter interface and output file formats won't change.
Old SIMPUTs will work as before

Current ETA: March

Hands-on session (preview)

Installation: SIXTE can run locally on Linux and MacOS, and is also available on the JHU SciServer (via the `sixte_users` group). For either case, see

`https://www.sternwarte.uni-erlangen.de/sixte/installation/`

Simulations following a Tutorial:

`https://www.sternwarte.uni-erlangen.de/~sixte/downloads/xrism_workshop/sixte_tutorial.pdf`

1. Getting started: point sources with Resolve and Xtend
2. Bright source simulations
3. Simulating the first light observation

Note: We use preliminary versions of the Cycle 1 instrument files. The scripts and SIXTE instrument configuration will be distributed once these files were made publicly available (on the SIXTE webpage).