Friedrich-Alexander-Universität
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SIXTE simulations of extended sources

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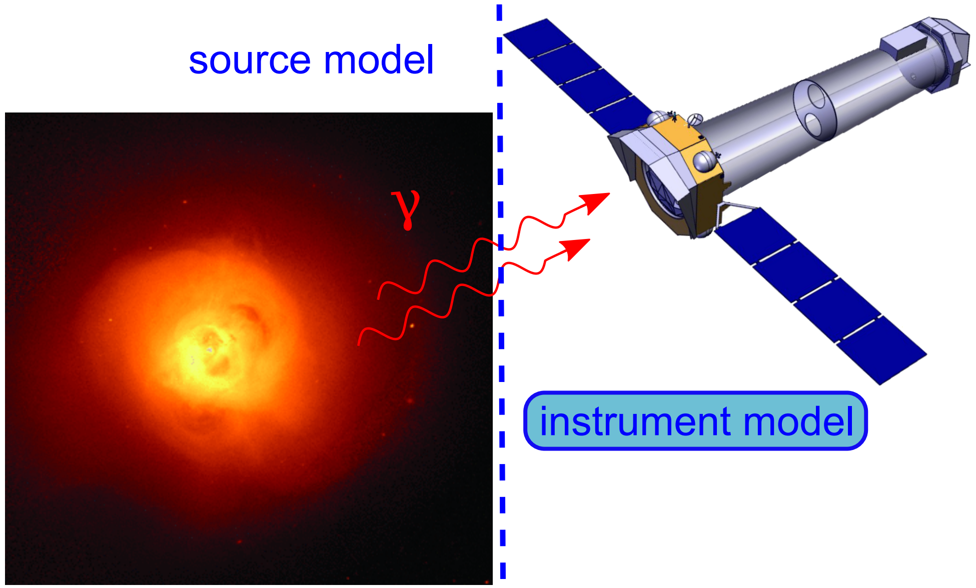
14 Jan 2026

What is SIXTE?



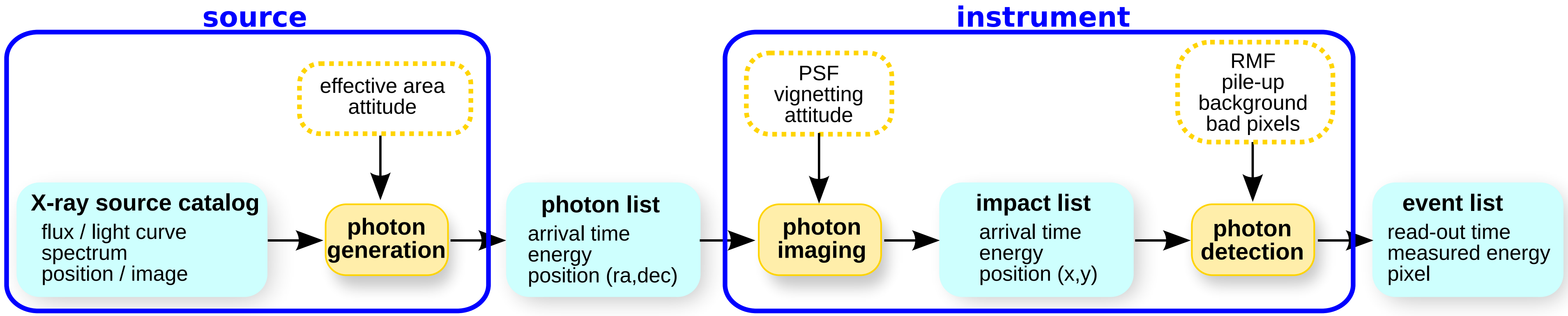
SImulation of X-ray TElescopes

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

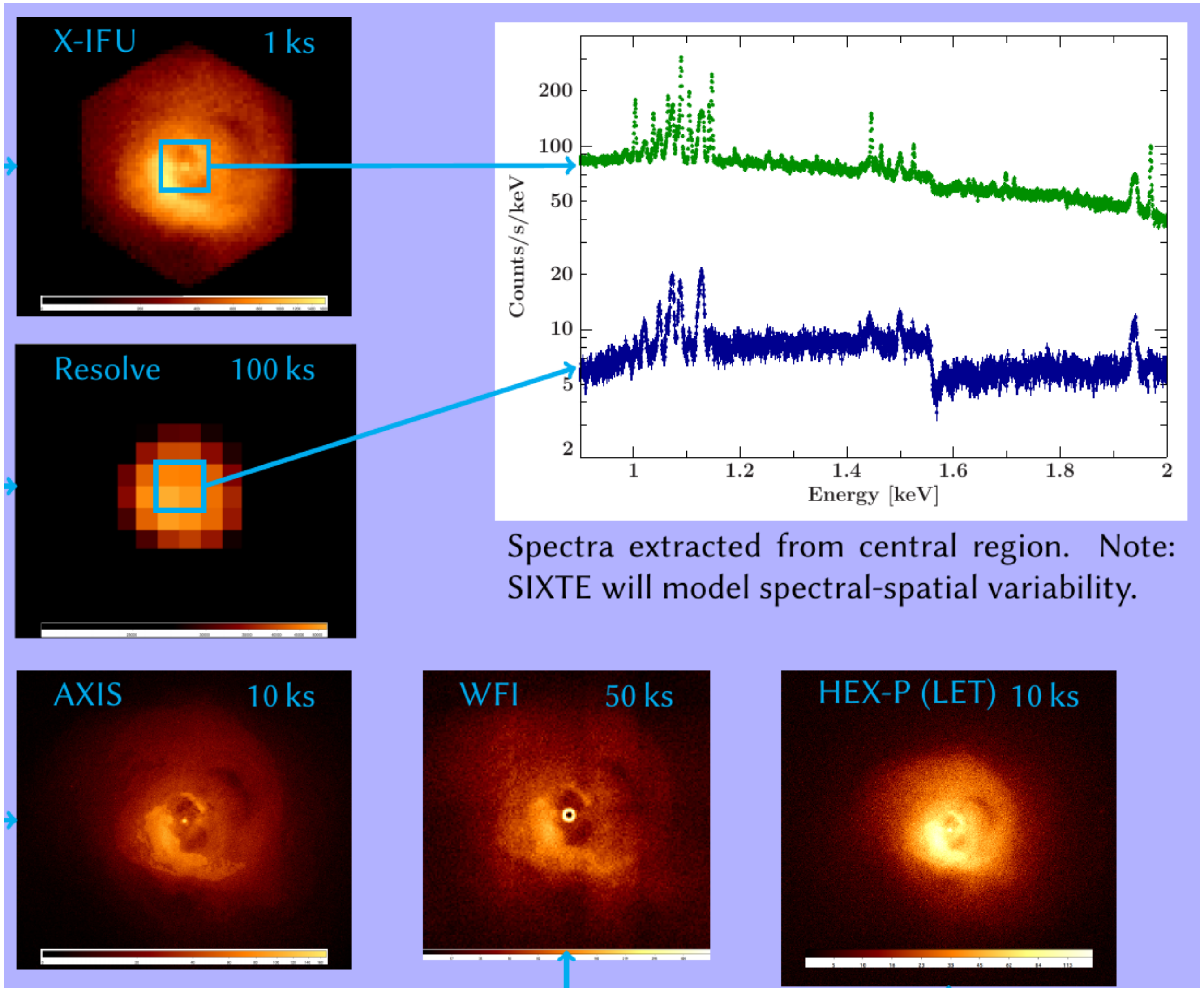
The simulation output are standard FITS files.

Tools for image creation, 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!



What is SIXTE?

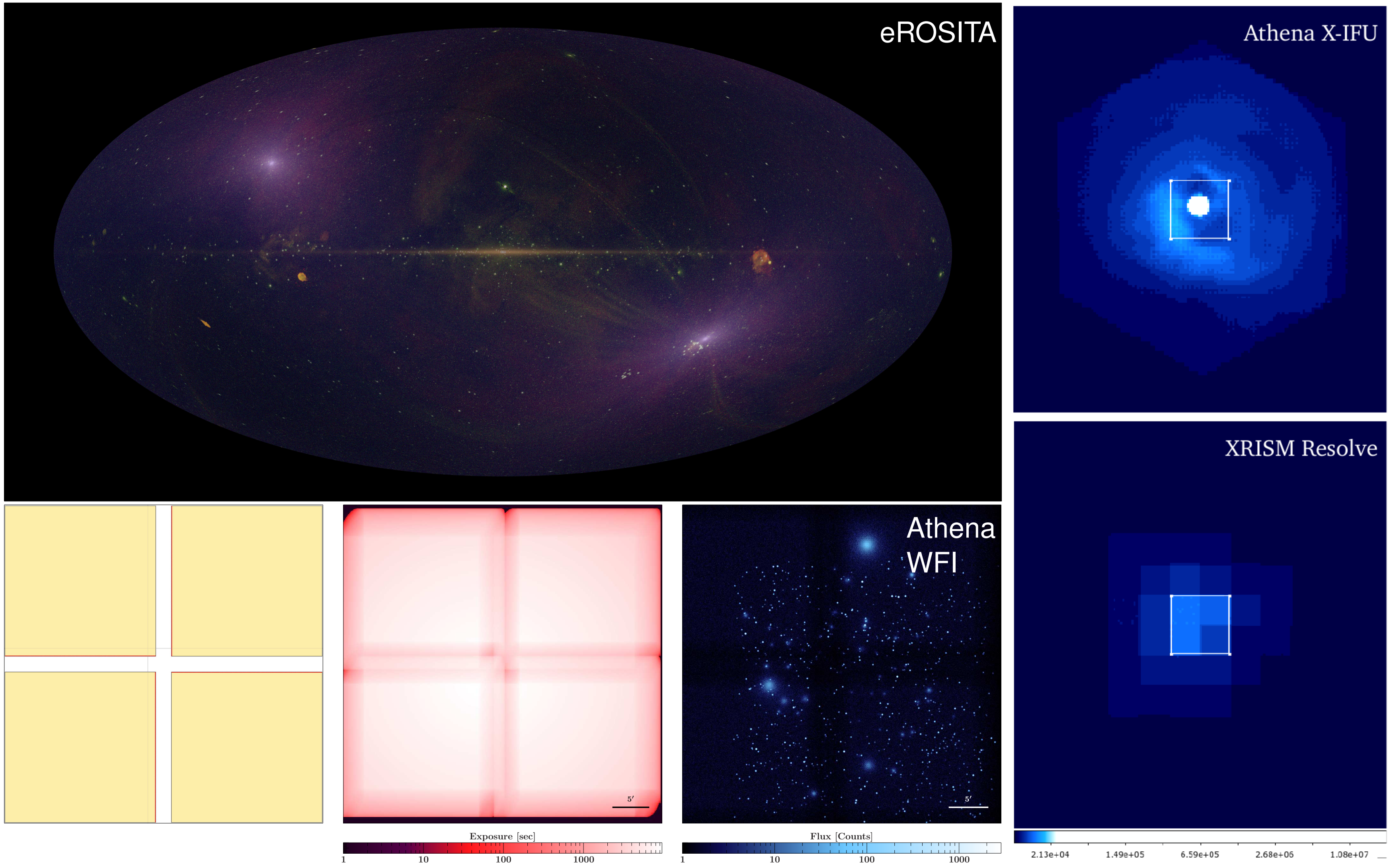


Spectra extracted from central region. Note: SIXTE will model spectral-spatial variability.

Use SIMPUT format to define instrument-independent sources.

Also supported by other tools: `simx`, `SOXS`, `MARX`, `pXSIM`

What is SIXTE?



Many types of simulation possible:

- all-sky simulation (*eROSITA*)
- deep survey (*Athena WFI*)
- galaxy cluster (*Athena X-IFU*, *XRISM Resolve*)

Who uses SIXTE?

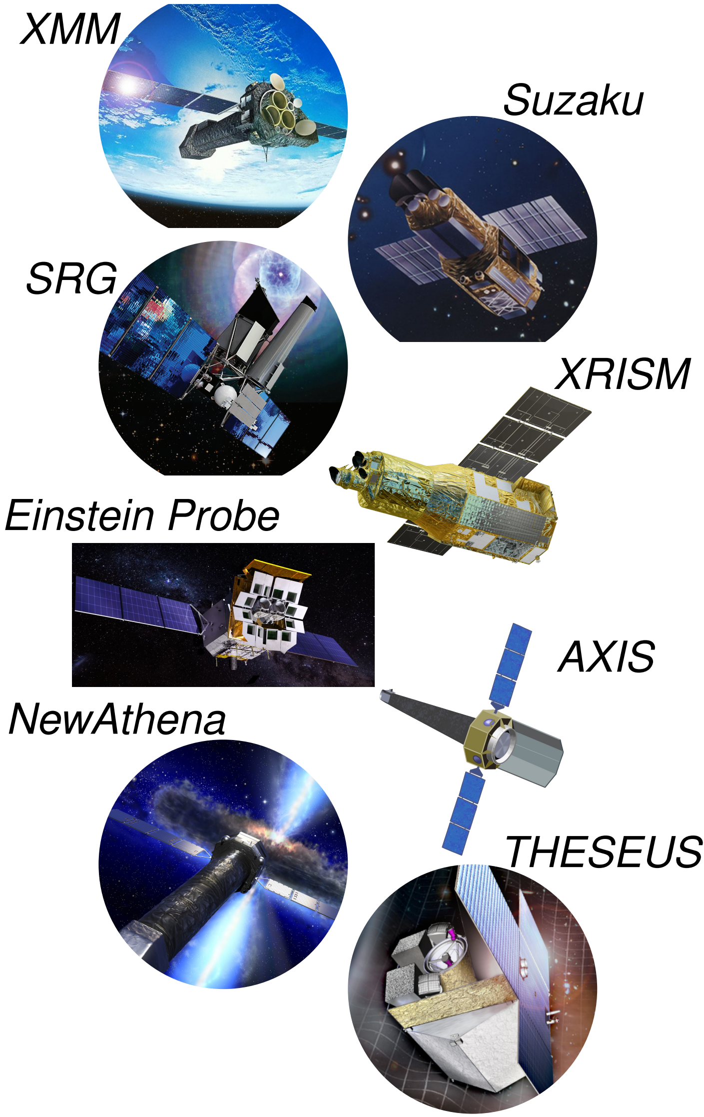
Main use case: assess performance of X-ray telescopes.

SIXTE is the official end-to-end simulator of many planned X-ray missions:

- *NewAthena* (DePFET Array *WFI*, Microcalorimeter *X-IFU*)
- *AXIS* (CCD Detector, *Chandra* successor)
- *THESEUS* (Lobster-Eye Telescope *SXI*, Coded Mask Instrument *XGIS*)

For *SRG/eROSITA*, SIXTE also provided mock data for ground segment software development.

For *XMM-Newton* and *XRISM*, SIXTE is used for proposal writing.



How to use SIXTE

Two main ways:

Local installation

Generally the recommended solution.
Either download the code and build it, or use our Docker container (`fausixte/sixte`) – see

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

Remote installation

SIXTE installations are available on the JHU SciServer and ESA Datalabs – contact the SIXTE support mailing list to join:

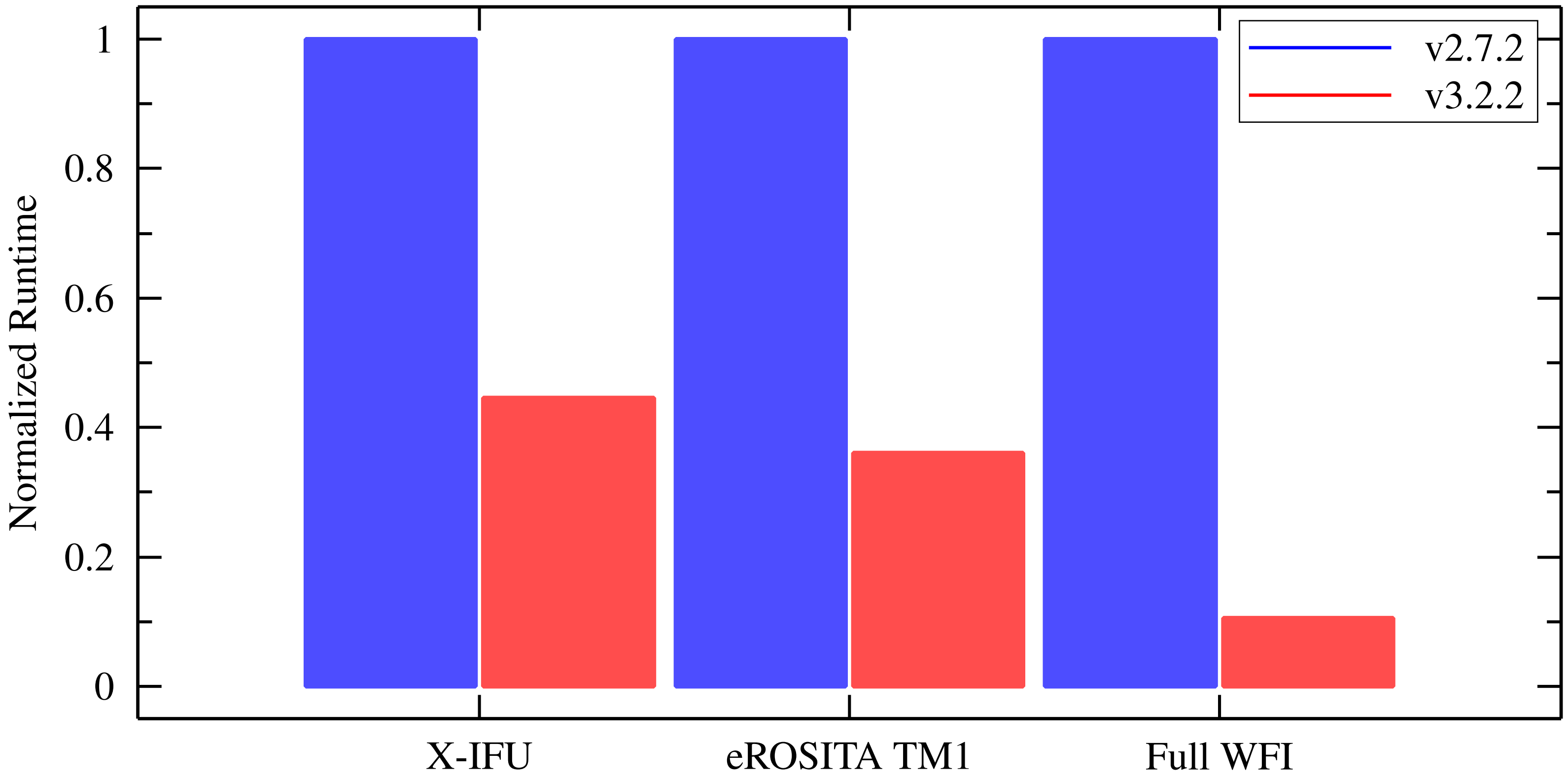
`sixte-support@lists.fau.de`

SIXTE development

In Nov 2024, released SIXTE version 3 after (mostly internal) refactoring.

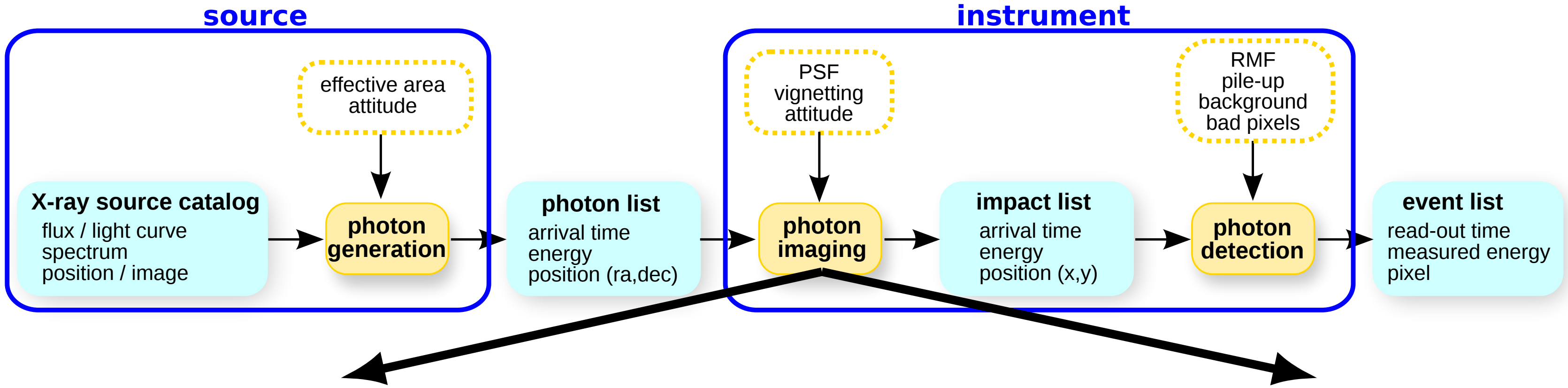
Since then, SIXTE received several updates, including support for new missions, tool upgrades and performance improvements (see right).

To stay up to date, subscribe to the SIXTE users mailing list (see Contact tab on the SIXTE webpage)

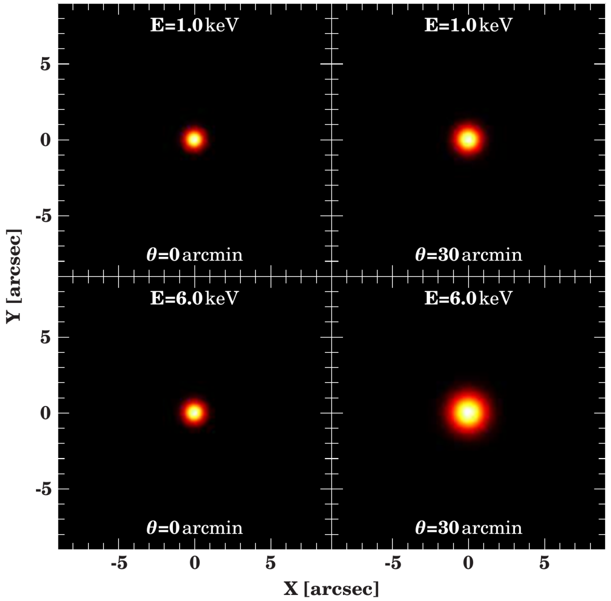


Run times of old and new SIXTE versions for selected simulations.

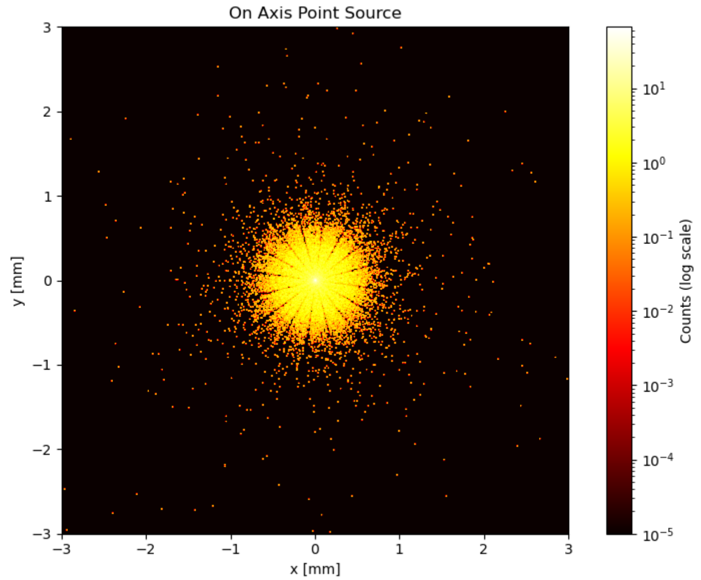
Ray Tracing



Old: PSF Sampling



New: Ray Tracer



Building extended source SIMPUTs

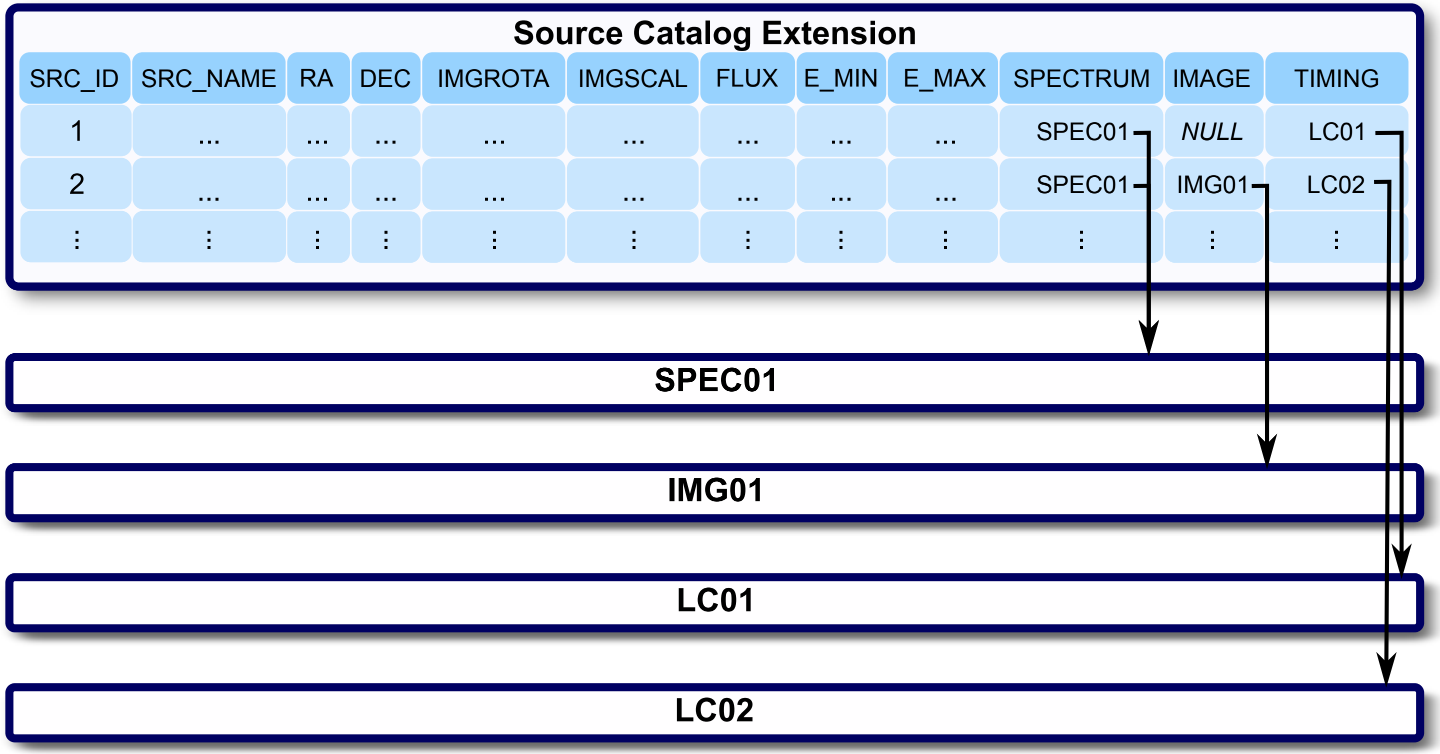
SIMPUT format

To build more complex SIMPUTs, need to understand the format.

A SIMPUT catalogue is made of multiple sources.

Sources always have a position, flux and spectrum.

Sources optionally have (scaled) image, and timing data.



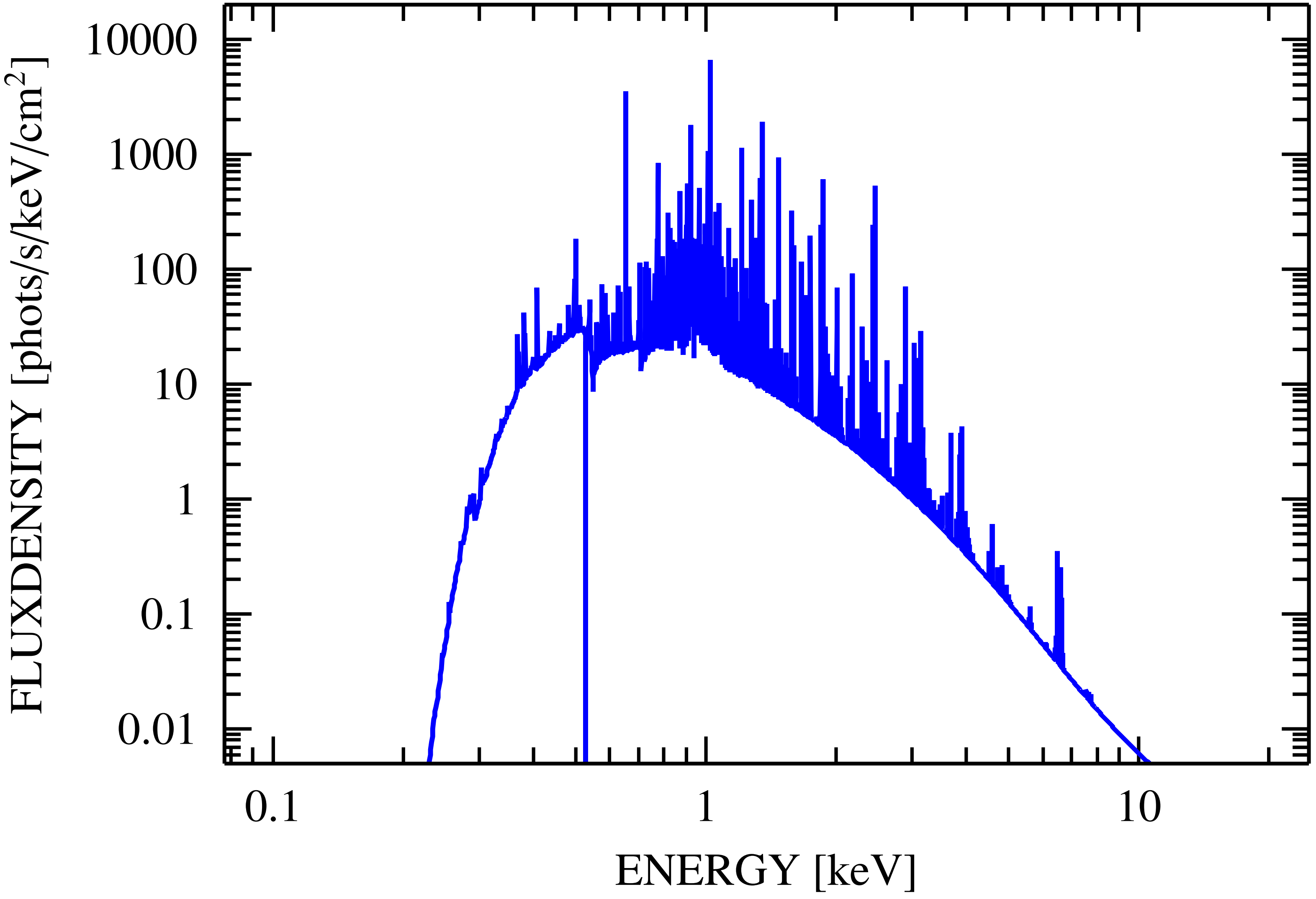
Defining a spectrum

In SPECTRUM extension, specify a spectrum via its flux density F(E).

SIXTE can build this from XSPEC/ISIS models or ASCII files.

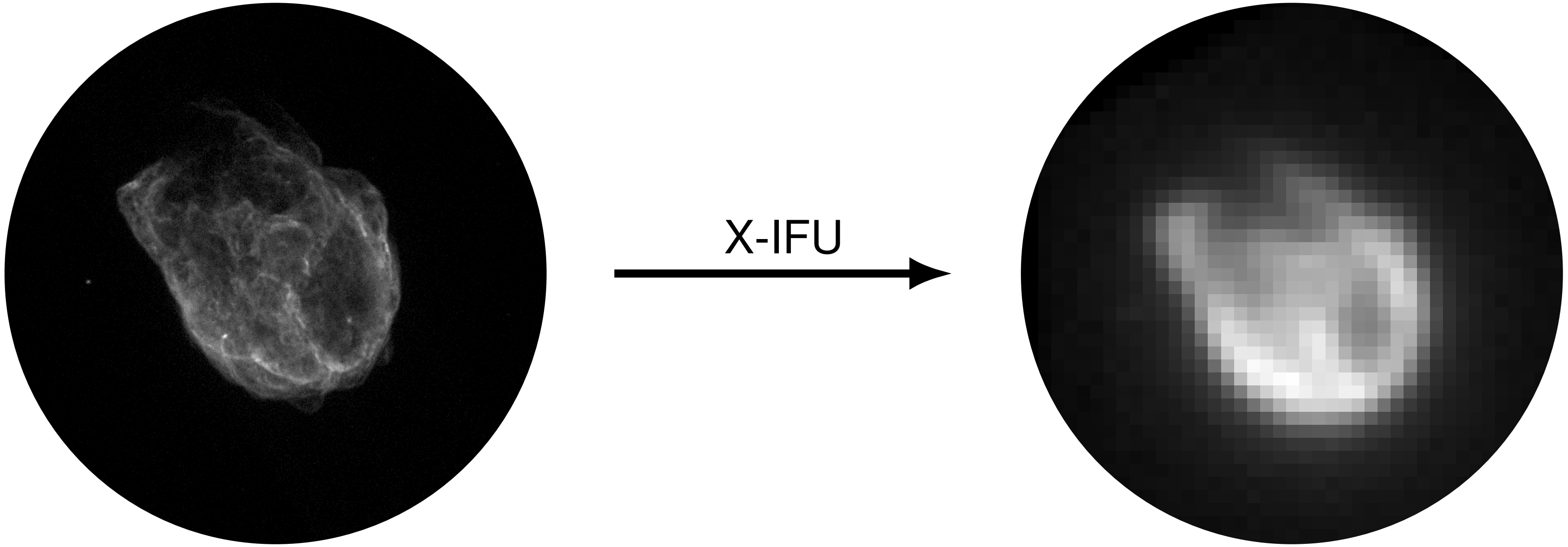
You can also write them yourself!

Note: Energy grid should be better than instrument spectral resolution!



Adding an image

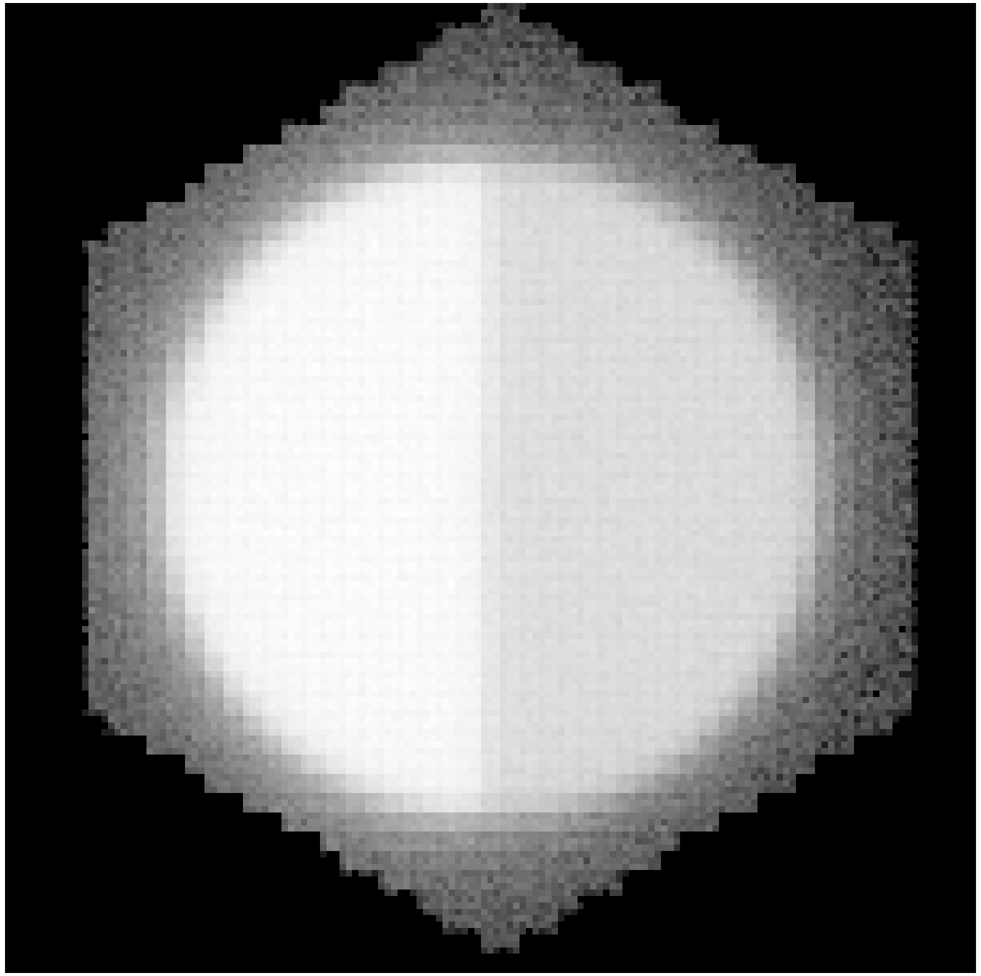
Simplest extended source: Attach an image to a point source. Here: Chandra image of LMC N132D



Problem: Spectrum does not vary with position!

Subdividing a source

To vary spectrum with position: Subdivide your source.



Divide one astronomical object into multiple sources in a SIMPUT catalogue.

Need to create separate images for each component. Note: Component images can also overlap, e.g., for 3D structures.

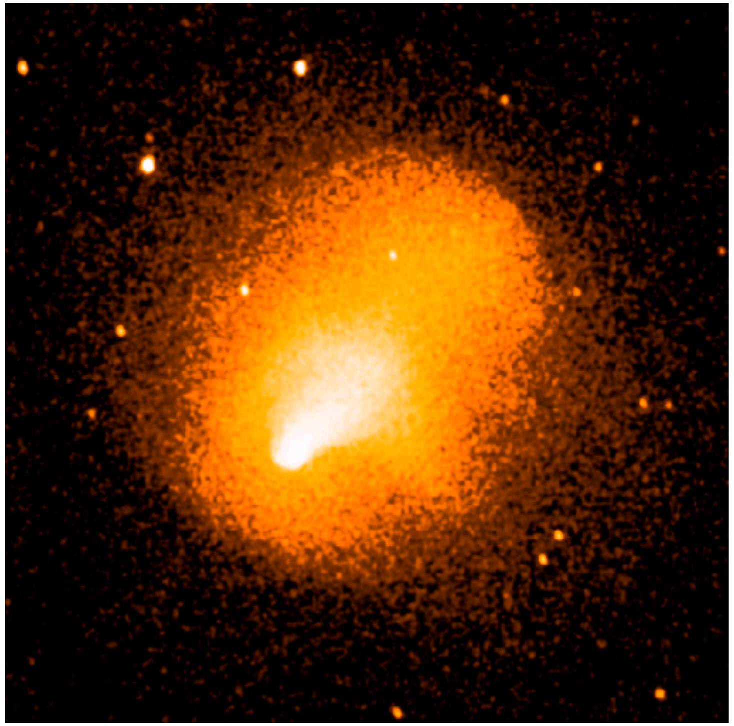
Example: Sphere divided into two hemispheres.

simputmultispec

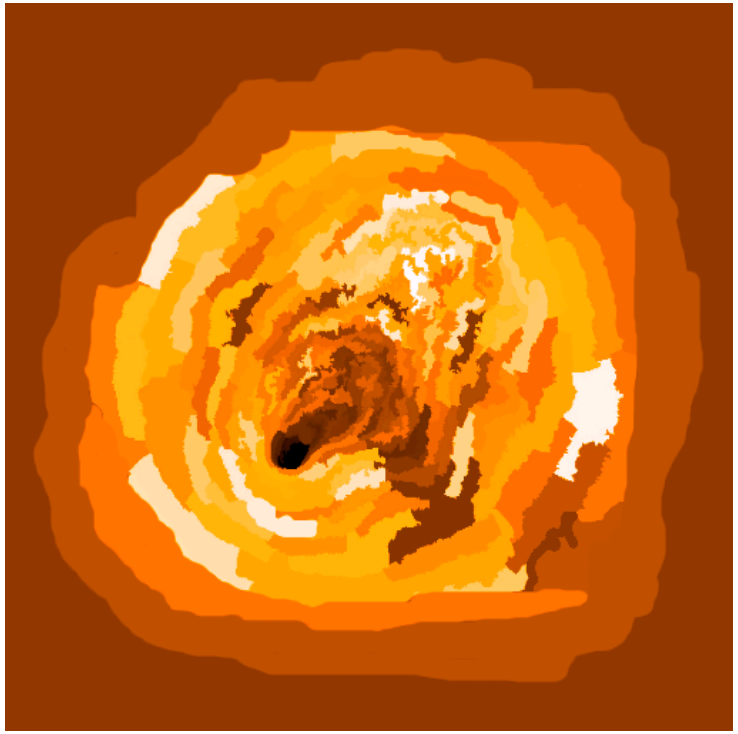
For creating extended source SIMPUTs subdivided by spectral parameters, use the tool `simputmultispec`.

Input: 2D maps of flux and spectral model parameters.

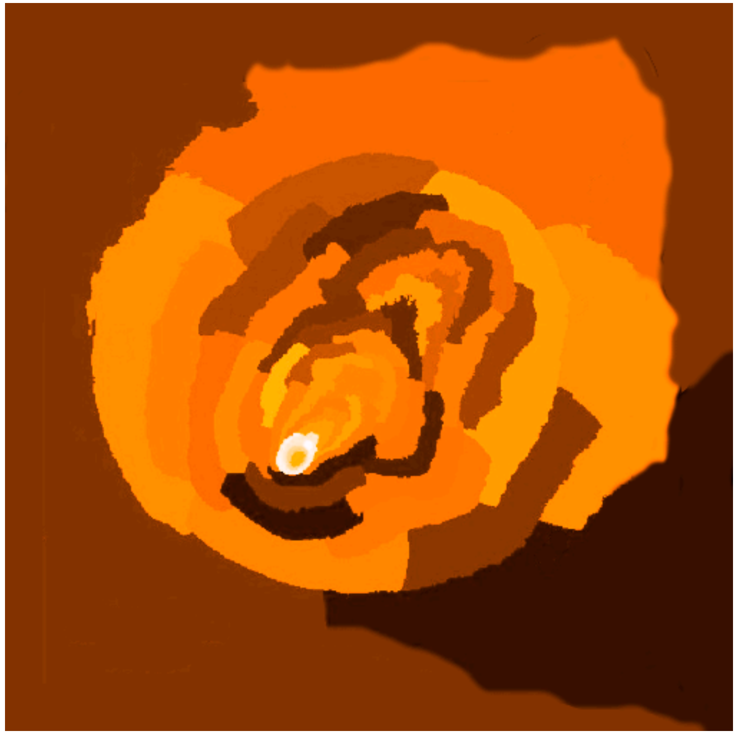
Example: Maps of kT and Metal abundances of Abell 2146 for an `apec` model.



Flux



Temperature



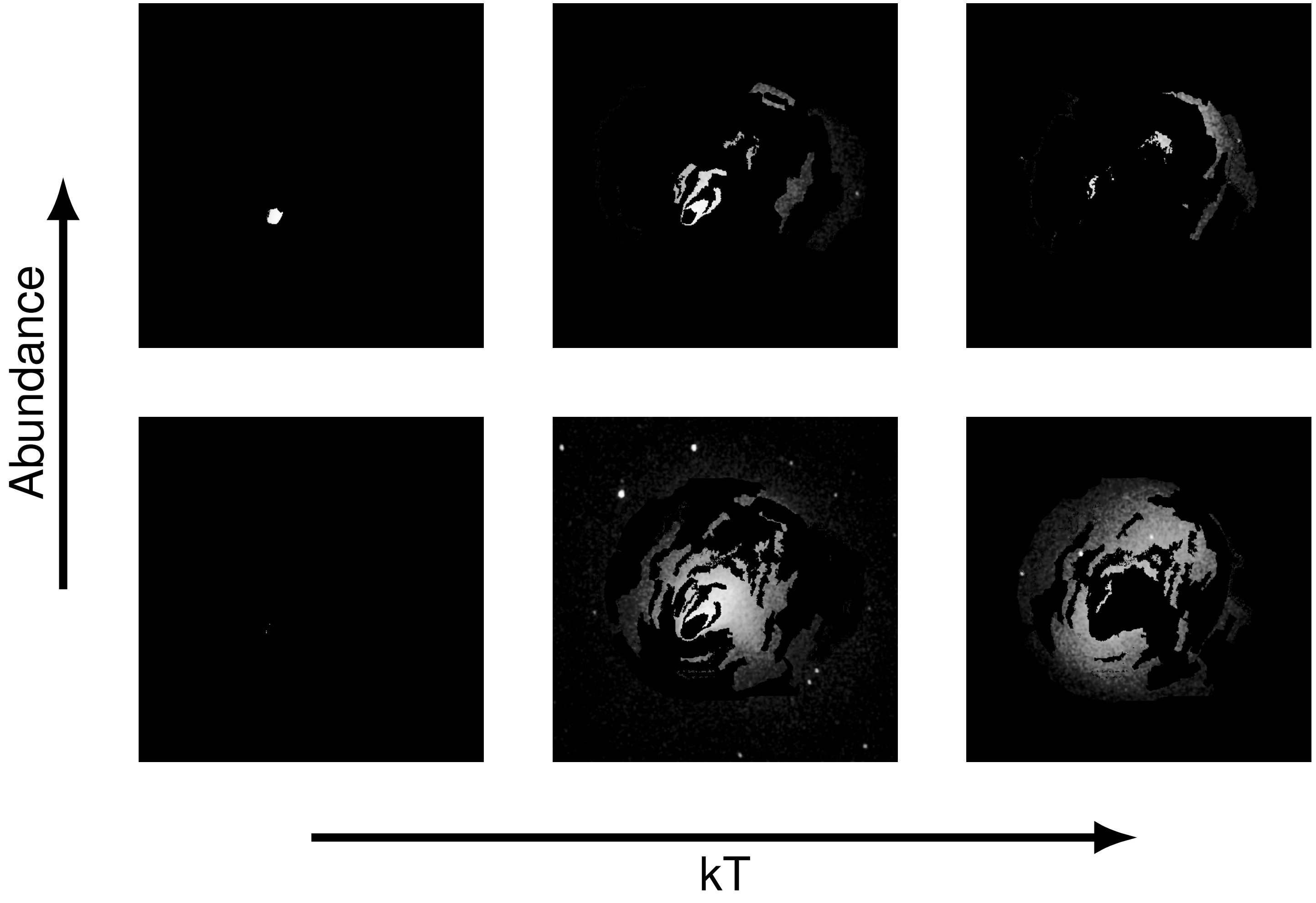
Metal Abundance

simputmultispec

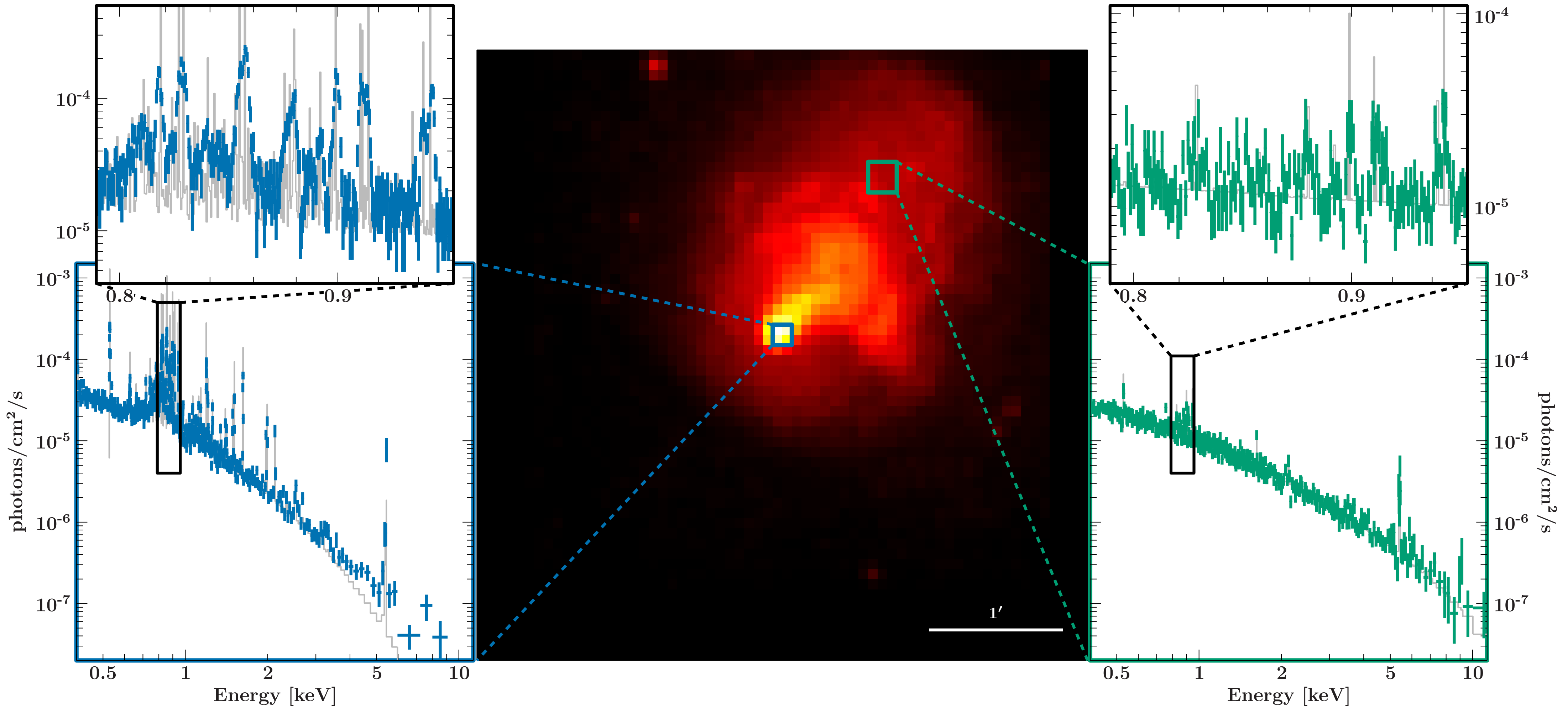
User supplies number of grid points to subdivide parameters into.

Here: Two abundances, three temperatures

`simputmultispec` subdivides image accordingly and generates spectra for each parameter combination, providing one output SIMPUT file.



X-IFU simulation of this SIMPUT shows spectra varying with position.



simputmulticell

Alternate approach: simputmulticell

Make a “cloud” of point sources with varying spectra. Useful for 3D models.

Example:
$\approx 10^6$ cells with a 100×100 parameter grid, only using 226 unique spectra.

Select / All / Invert	RA D degrees Modify	DEC D degrees Modify	FLUX D ergs/cm2/keV/s Modify	T D keV Modify	FE_ABUND D Modify	NORM D Modify
1	-4.110574178312E-02	-4.110573120442E-02	6.812160145550E-19	4.014013011249E+00	2.362533390184E-01	8.273424697005E-10
2	-4.110488700352E-02	-4.110487642549E-02	7.023374075892E-19	4.048186638619E+00	2.379074157530E-01	8.529945757918E-10
3	-4.110403225948E-02	-4.110402168210E-02	7.242389323389E-19	4.082268053230E+00	2.395803130322E-01	8.795941582877E-10
4	-4.110317755098E-02	-4.110316697426E-02	7.469531677714E-19	4.116247984070E+00	2.412722386270E-01	9.071807846126E-10
5	-4.110232287802E-02	-4.110231230197E-02	7.705141579676E-19	4.150117149813E+00	2.429833987510E-01	9.357958015837E-10
6	-4.110146824061E-02	-4.110145766521E-02	7.949574787494E-19	4.183866267014E+00	2.447139977232E-01	9.654824163304E-10
7	-4.110061363874E-02	-4.110060306400E-02	8.203203069993E-19	4.217486058390E+00	2.464642376077E-01	9.962857804829E-10
8	-4.109975907240E-02	-4.109974849833E-02	8.466414927209E-19	4.250967261163E+00	2.482343178278E-01	1.028253077691E-09
9	-4.109890454160E-02	-4.109889396819E-02	8.739616338824E-19	4.284300635465E+00	2.500244347543E-01	1.061433614523E-09
10	-4.109805004634E-02	-4.109803947358E-02	9.023231540737E-19	4.317476972773E+00	2.518347812649E-01	1.095878914777E-09
11	-4.109719558660E-02	-4.109718501450E-02	9.317703829963E-19	4.350487104365E+00	2.536655462748E-01	1.131642817243E-09
12	-4.109634116240E-02	-4.109633059096E-02	9.623496397894E-19	4.383321909785E+00	2.555169142367E-01	1.168781576897E-09
13	-4.109548677372E-02	-4.109547620294E-02	9.941093191808E-19	4.415972325299E+00	2.573890646070E-01	1.207353969534E-09
14	-4.109463242056E-02	-4.109462185044E-02	1.027099980429E-18	4.448429352313E+00	2.592821712788E-01	1.247421399793E-09
15	-4.109377810293E-02	-4.109376753347E-02	1.061374439002E-18	4.480684065759E+00	2.611964019782E-01	1.289048012494E-09
16	-4.109292382082E-02	-4.109291325202E-02	1.096987860911E-18	4.512727622413E+00	2.631319176229E-01	1.332300807213E-09
17	-4.109206957422E-02	-4.109205900608E-02	1.133997859588E-18	4.544551269134E+00	2.650888716411E-01	1.377249755937E-09
18	-4.109121536315E-02	-4.109120479566E-02	1.172464595151E-18	4.576146351019E+00	2.670674092490E-01	1.423967923629E-09
19	-4.109036118758E-02	-4.109035062076E-02	1.212450875887E-18	4.607504319432E+00	2.690676666840E-01	1.472531591469E-09
20	-4.108950704753E-02	-4.108949648136E-02	1.254022261704E-18	4.638616739919E+00	2.710897703933E-01	1.523020382507E-09

Problem: Both tools scale poorly with many independent parameters.

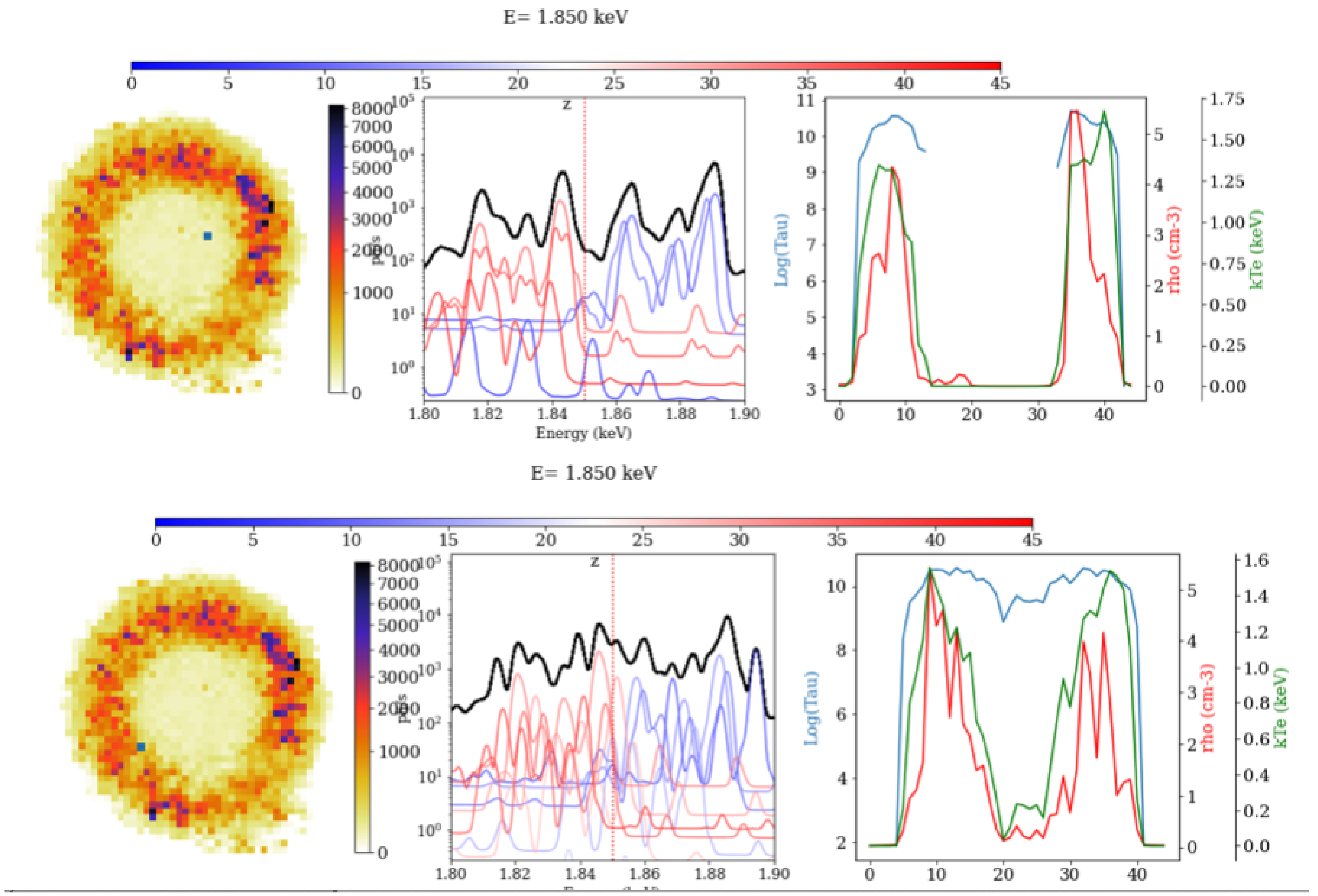
Custom approaches

Extreme example: Use 3D simulations of extended sources

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!

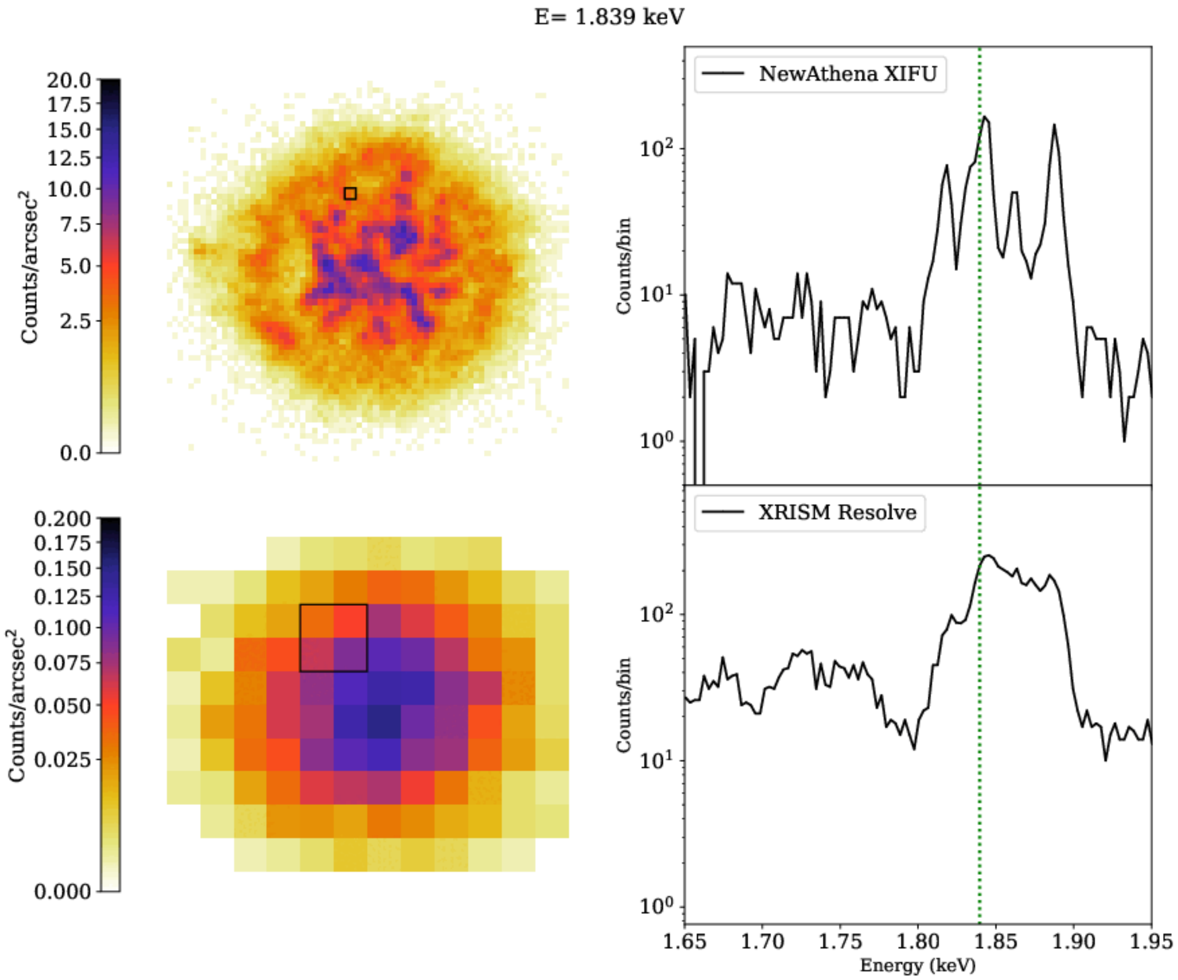


Custom approaches

Extreme example: Use 3D simulations of extended sources

After simulation, make subimages scanning over Si-Line

⟹ 3D tomography



Photon Lists

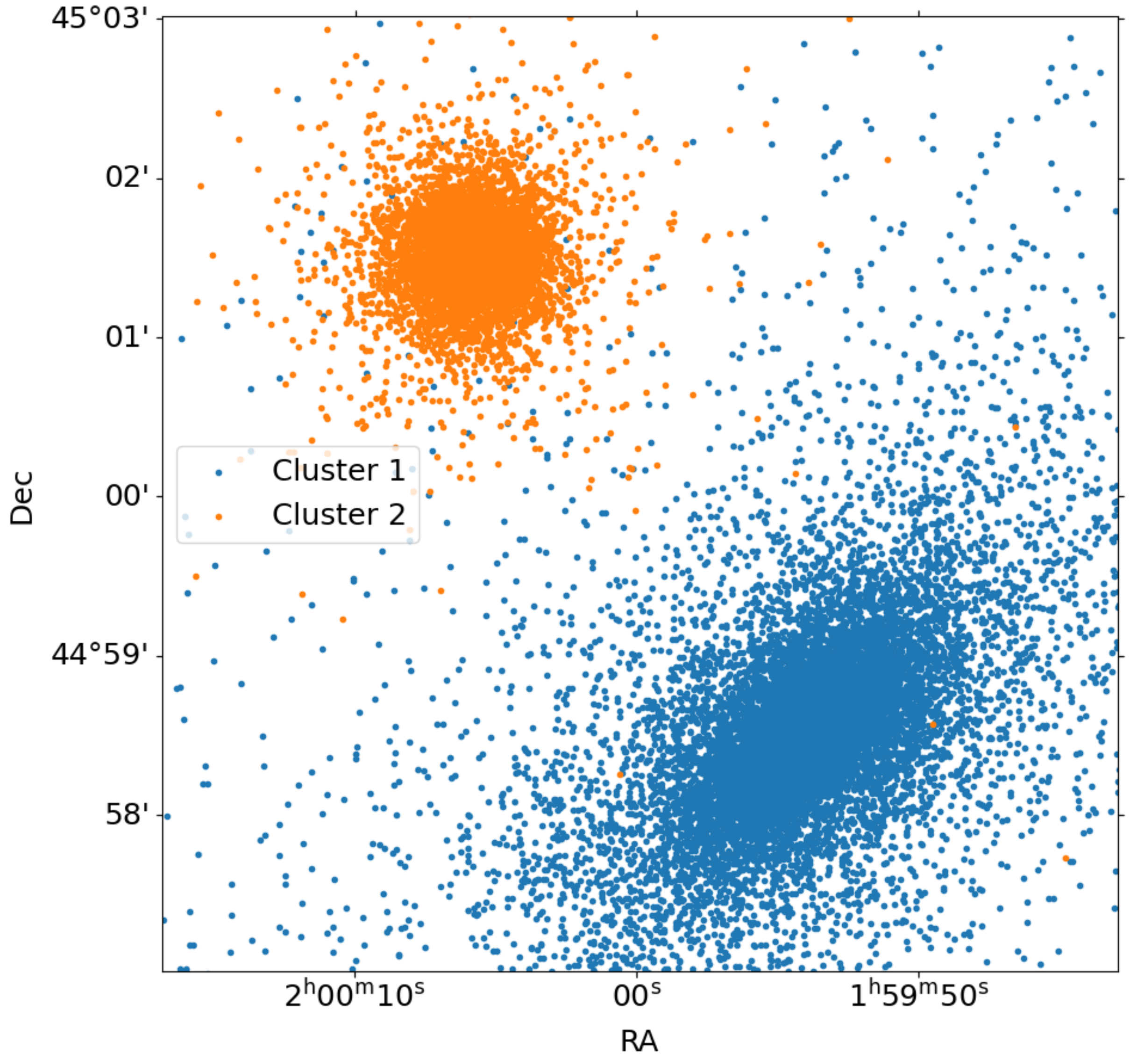
SIMPUTs can also use photon lists.

You can use photons lists instead of the `SPECTRUM`, `IMAGE`, or `TIMING` columns.
SIXTE then samples from this list instead of generating photons itself.

This gives maximum flexibility, BUT:

- Photon lists must be mission independent, so generated with a “flat” effective area.
- To avoid resampling photons, photon lists must contain many more photons than you expect to observe!

Example: Photon lists generated using the SOXS package.



Running simulations

Running Simulations

Often the simplest part of the workflow. Things to consider:

- Instrument mode
  Filter? Defocussing?
- Exposure time
  One exposure? Multiple GTIs?
- Pointed or slewing observation?

Once decided, simply run `sixtesim`.

Analyzing simulations

Analyzing simulations

Generally: SIXTE event files are FITS files!

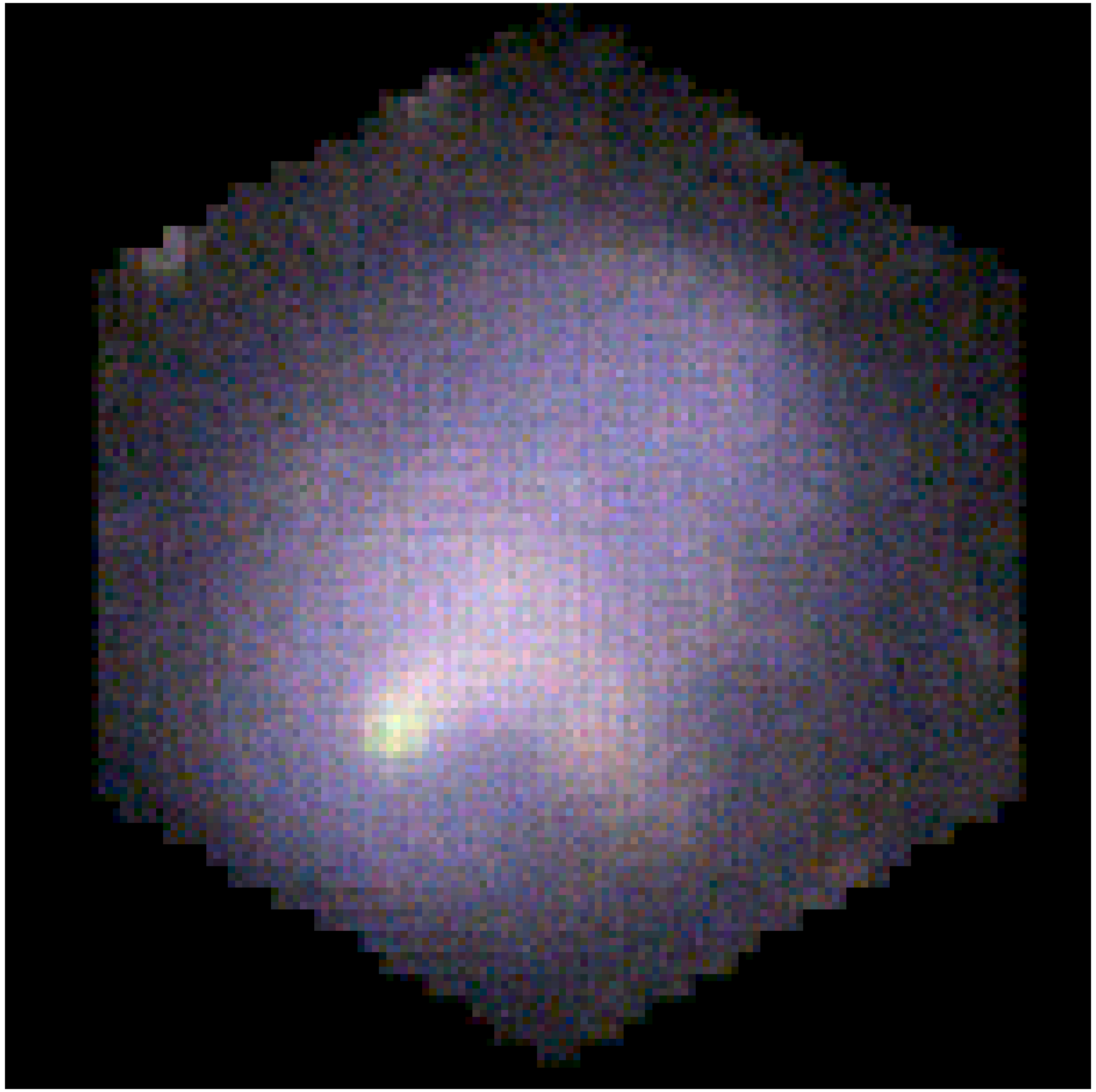
You can analyze them with anything that can read FITS!

For some common tasks, prewritten tools are available.

Making images

Use the imgev tool.

Using the FITS extended filename syntax, can also easily extract images in energy bands!

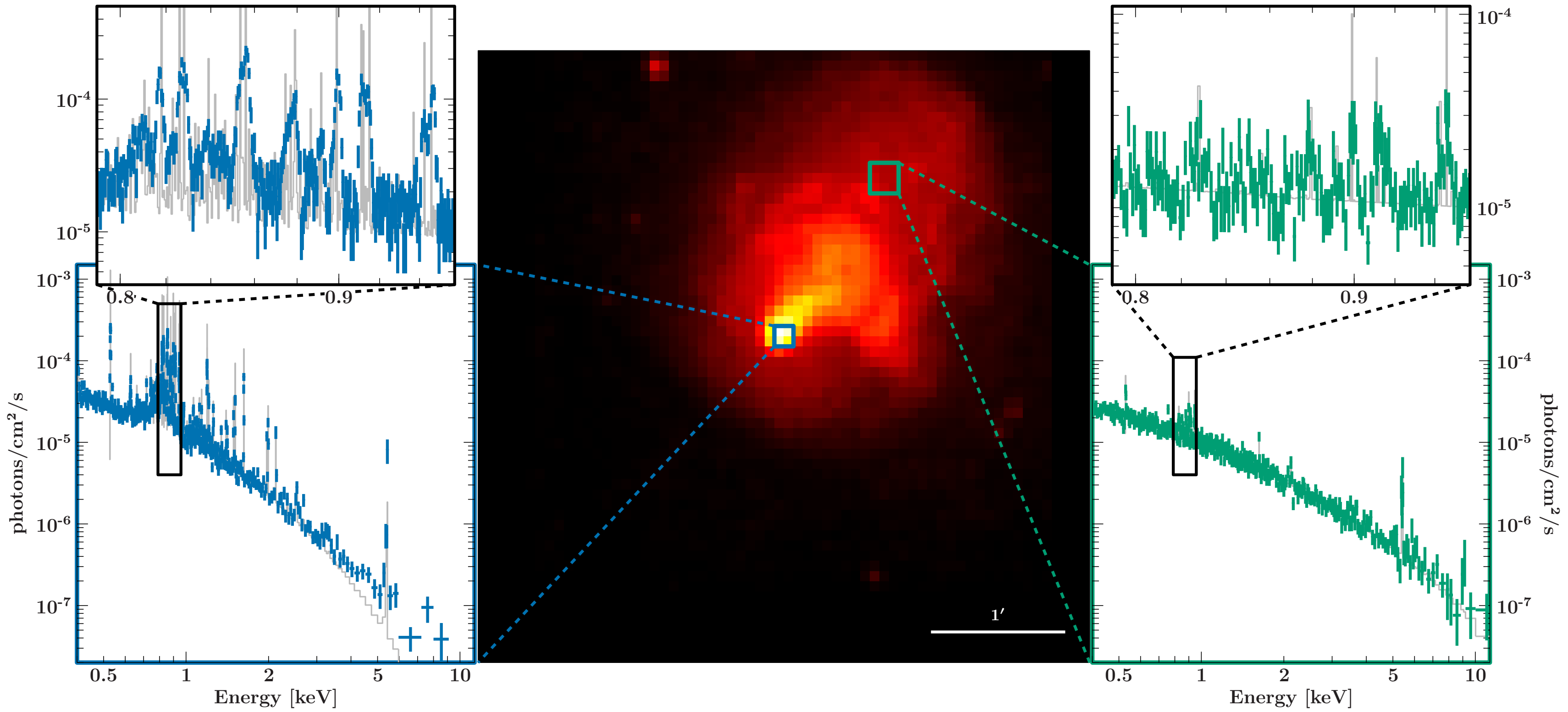


Extracting spectra

Use the `makespec` tool.

Using the FITS extended filename syntax, can also easily extract spectra for individual pixels, events of a given grade, ...

Also includes support for region and GTI files.

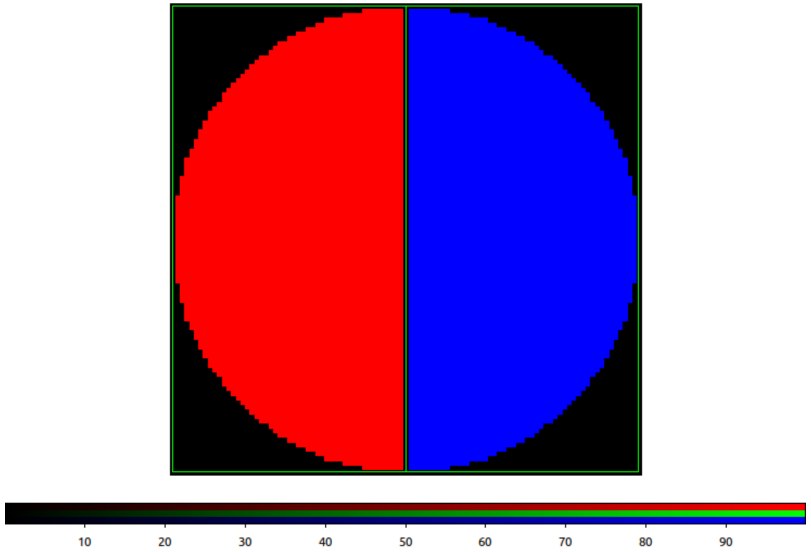


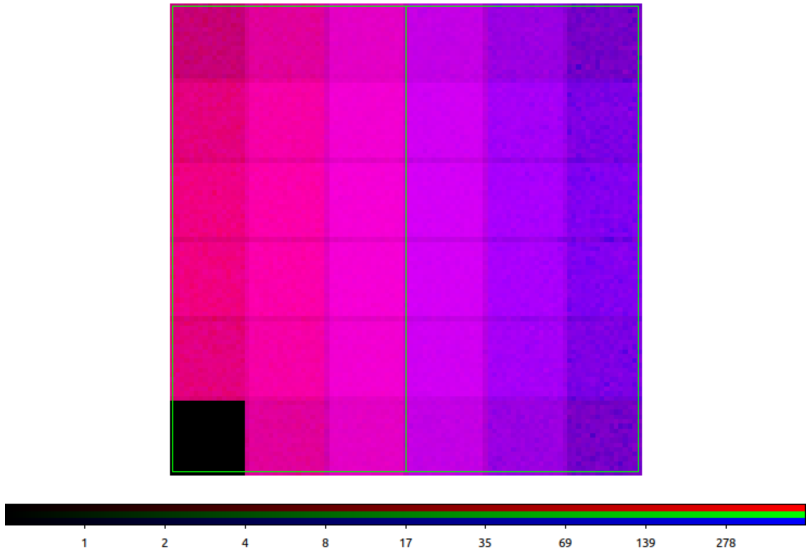
Extracting ARFs

For more complex sources, spatial-spectral mixing becomes a problem – see talk by F. Mernier.

Simplified problem: Imagine source split into two regions, red and blue.

Resolve image shows strong cross-contamination of source extraction regions - need to fit both simultaneously!

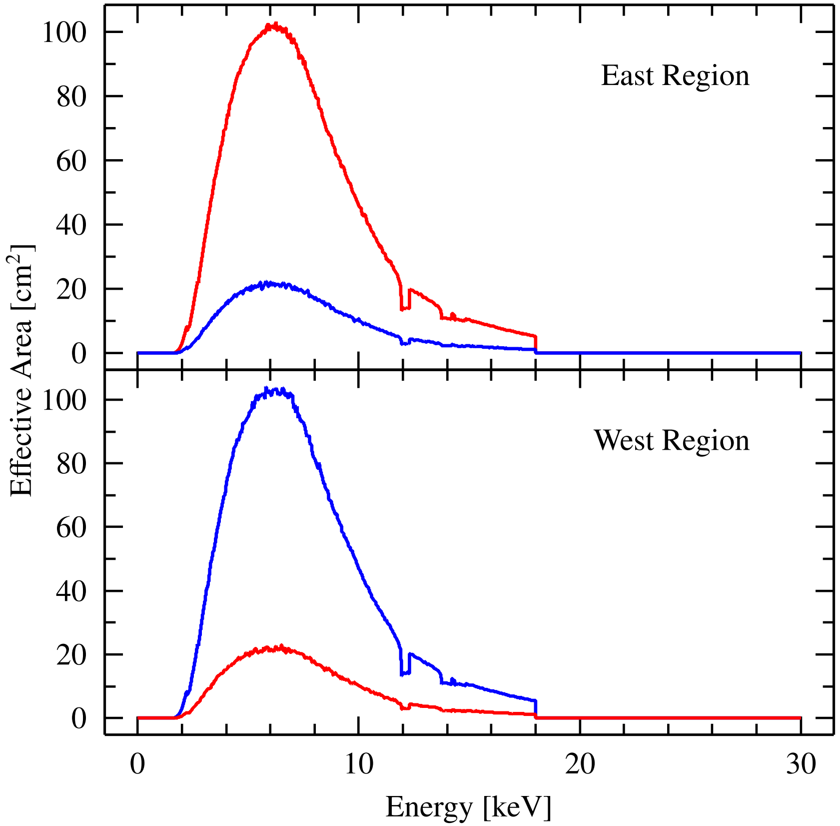




Extracting ARFs

The tool sixte_arfgen allows extraction of the relevant ARF files for such spectral fits:

For a given observation (including attitude!), detector and source (either point source, or source described by a SIMPUT file), calculate the ARF of this source in a given region.



Extracting ARFs

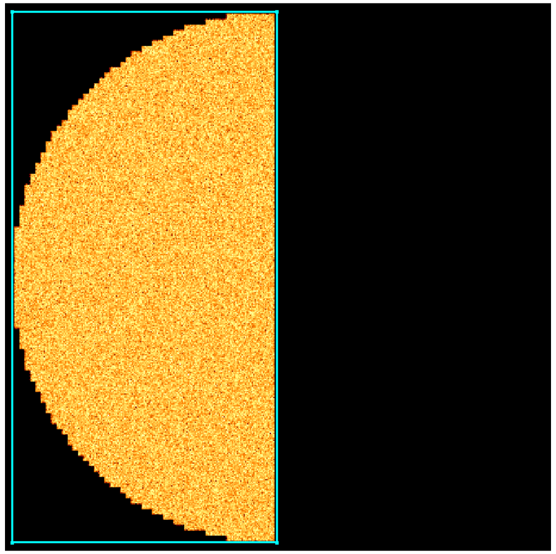
ARFs are generated in a Monte Carlo approach: For every N_{bin}th ARF bin, generate N_{phot} photons, evenly spaced across observation duration.

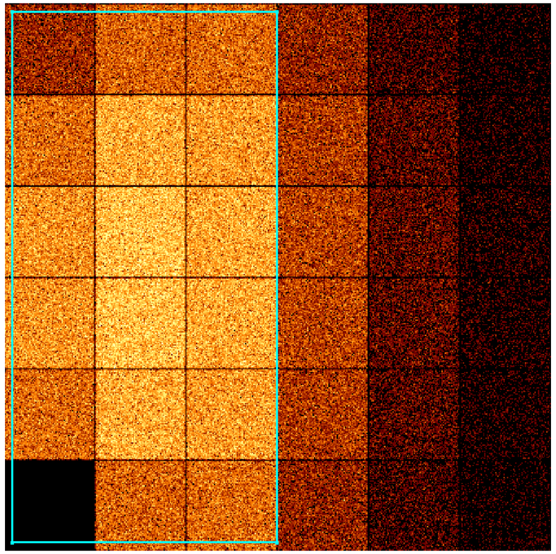
The fraction of photons that hit the detector and were reprojected into the given sky region are used to calculate a modified ARF.

Example (right):

- Generate 100k 2 keV photons from source
- 98k photons are imaged by telescope
- 69k photons reach detector
- 55k photons are reprojected into target region

$\Longrightarrow$ At 2 keV, generated ARF value is 55 % of on-axis ARF.



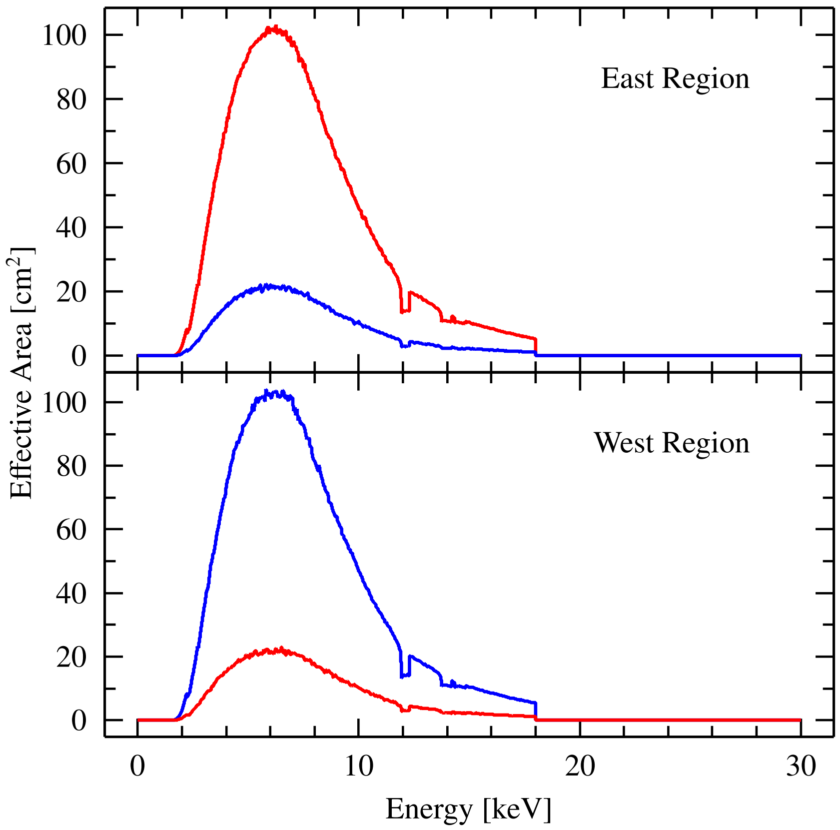


Extracting ARFs

Note: Due to Monte Carlo approach, generated ARFs are subject to sampling noise.

Need to use many test photons, depending on use-case.

Can also generate multiple ARFs on a larger cluster and calculate average.



Additional Information

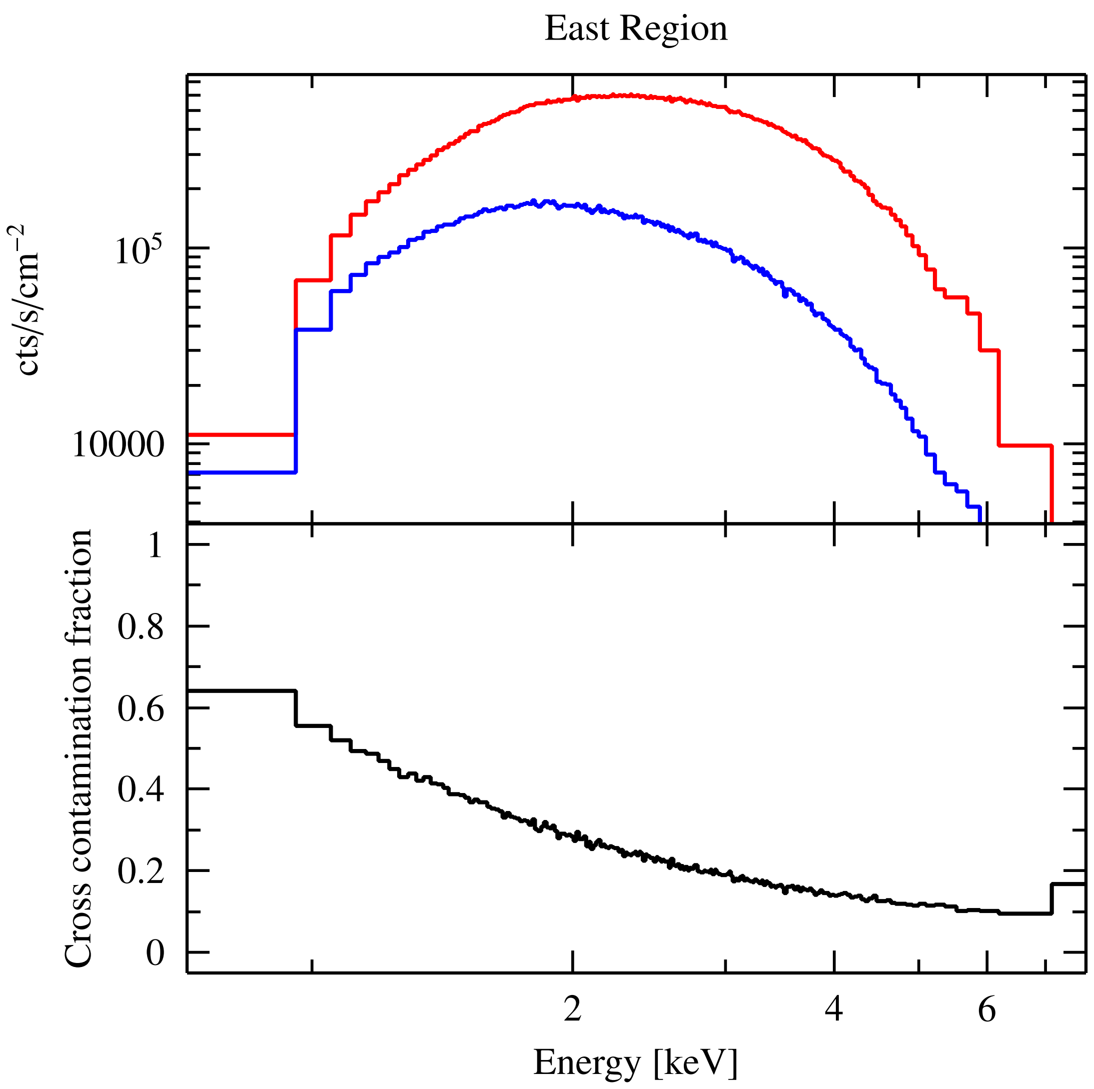
SIXTE can optionally write out some intermediate products:

- List of generated photons
- List of photon impacts on the focal plane

Photons are also tracked through the simulation with a unique photon ID and the ID of their SIMPUT source.

This can be useful!

Example: Estimate the degree of cross-contamination in one region of our previous example.



Summary

Most complex part of extended source simulations is **generating the SIMPUT**

For certain approaches, we already have existing tools (`simputmultispec`, `simputmulticell`).

Otherwise: SIMPUTs are FITS files – once you understand the format, you can make your own.

When analyzing data, especially spectra, **consider spatial-spectral mixing**

Use the `SRC_ID` in event files to track this, and `sixte_arfgen` for spectral fitting.

Thank you for your attention!