Friedrich-Alexander-Universität
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SIXTE simulations of compact objects

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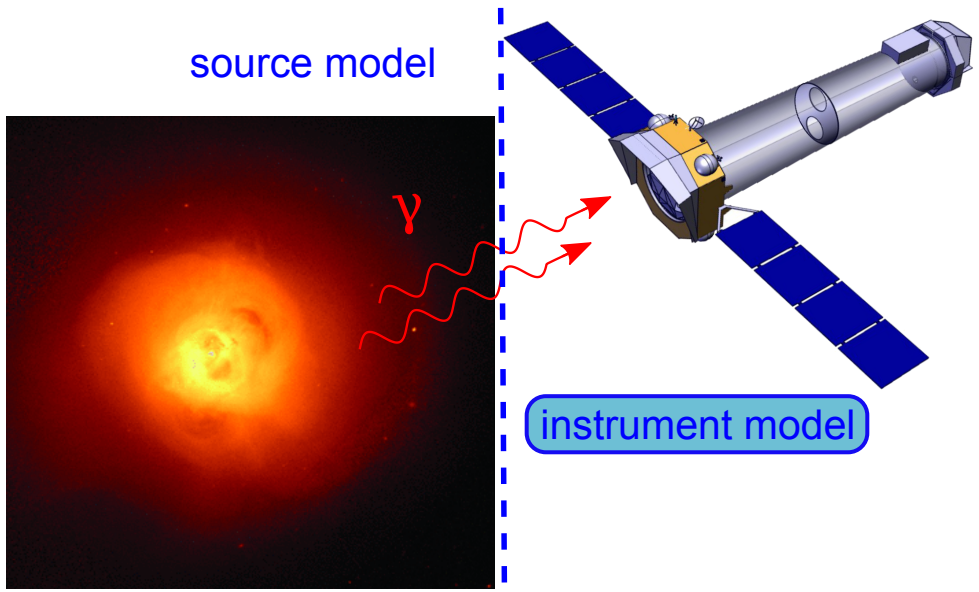
02 Jun 2026

What is SIXTE?



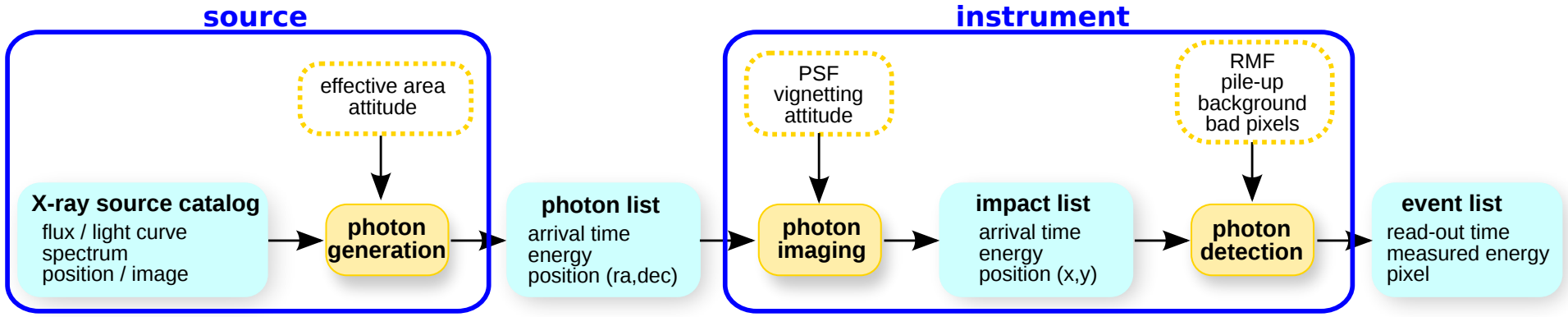
SImulation of X-ray TElescopes

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

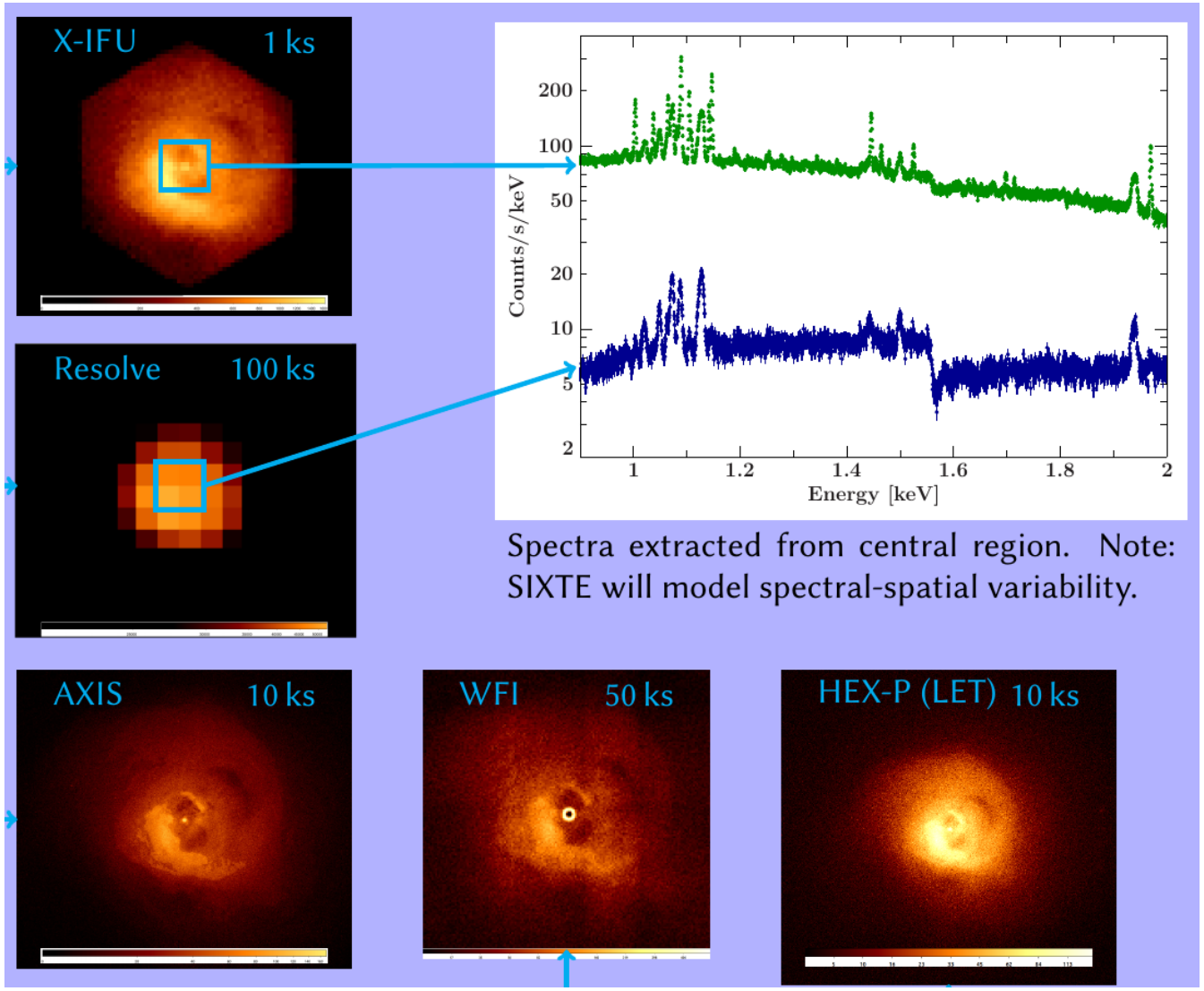
The simulation output are standard FITS files.

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?

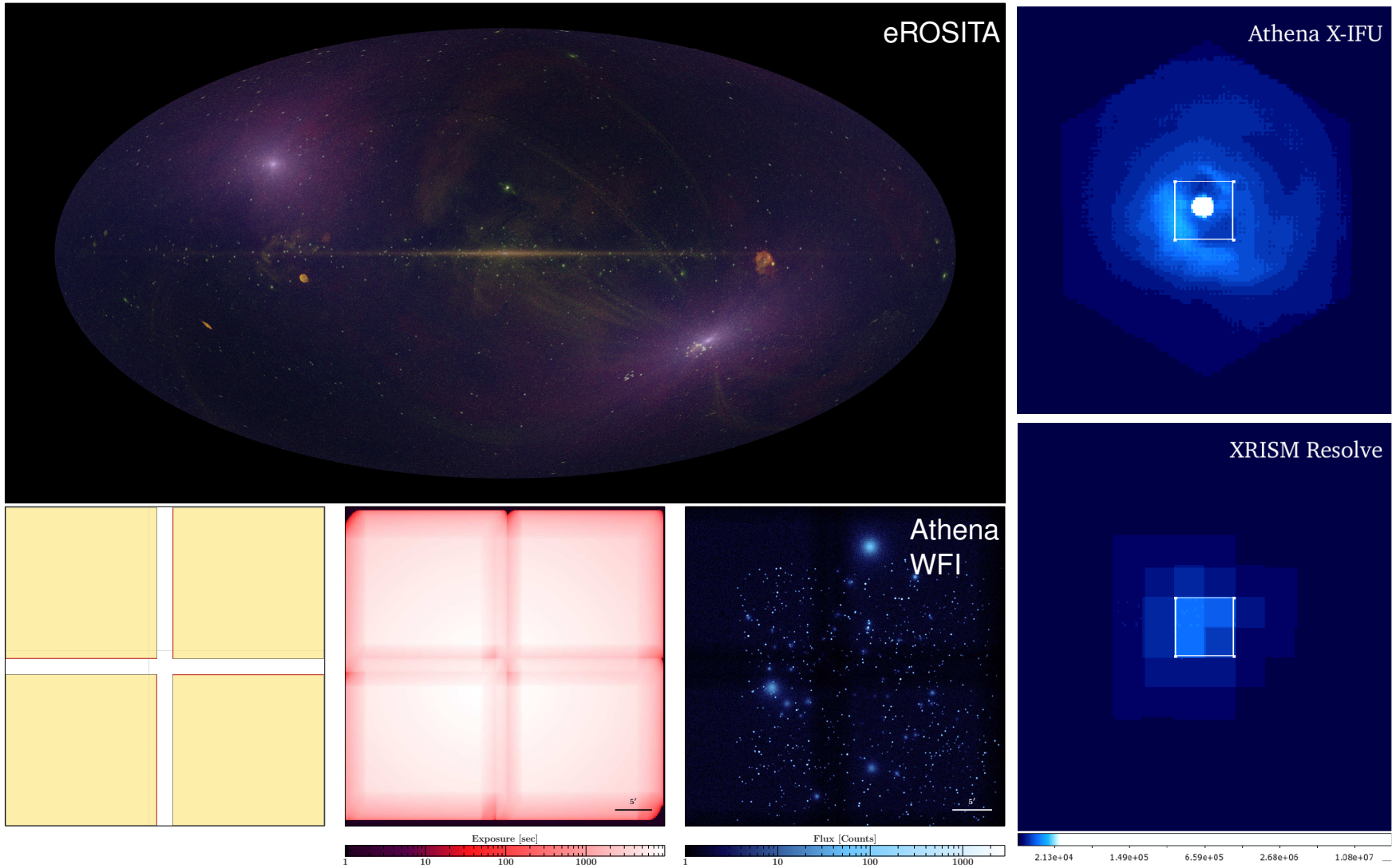


Spectra extracted from central region. Note: SIXTE will model spectral-spatial variability.

Use SIMPUT format to define instrument-independent sources.

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

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?

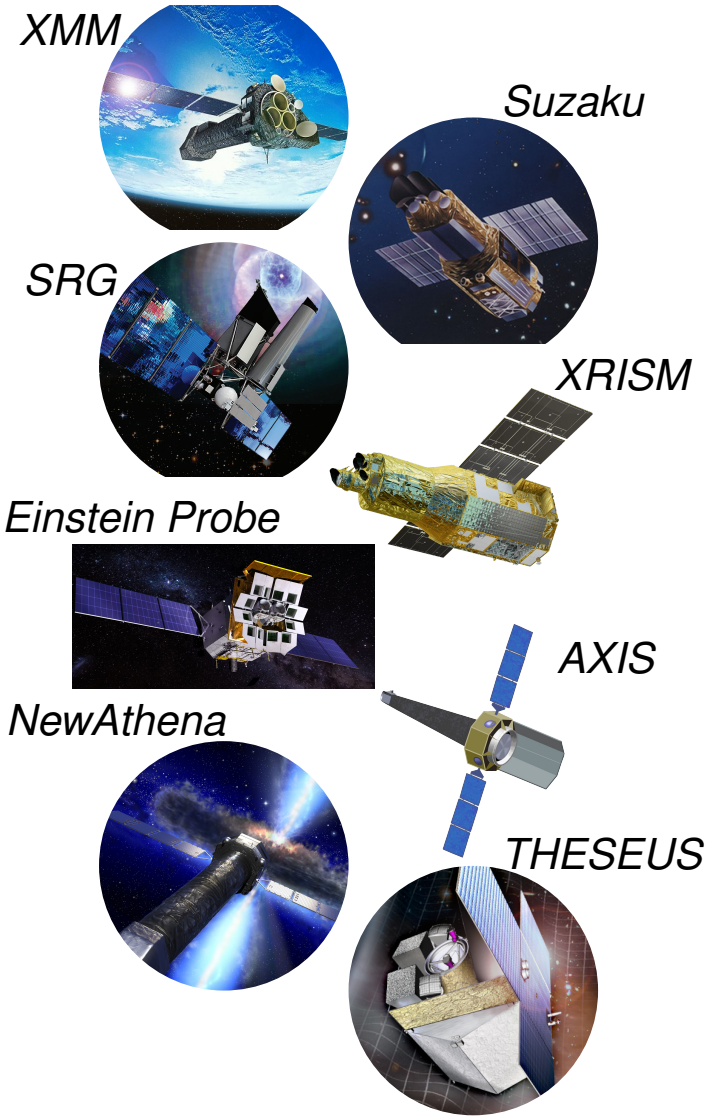
Main use case: assess performance of X-ray telescopes.

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

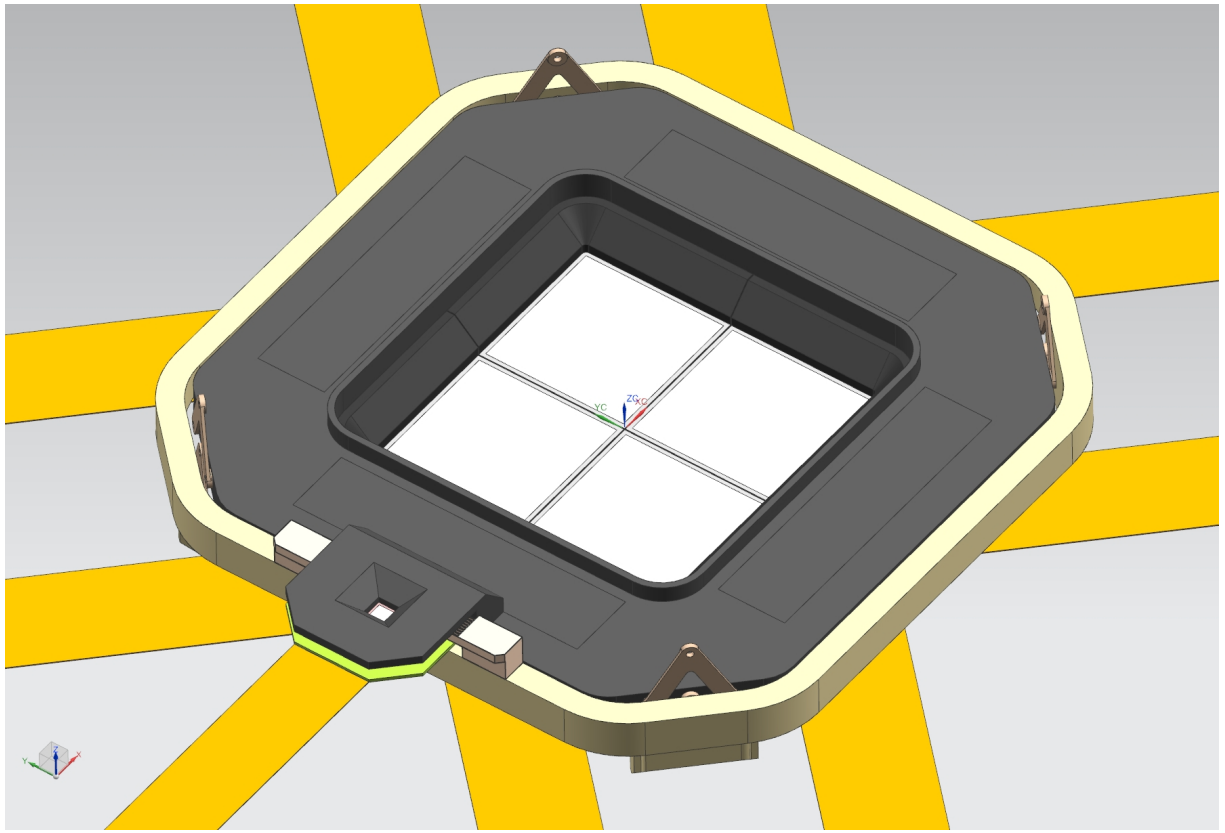
SIXTE installations are available on the JHU SciServer and ESA Datalabs – contact the SIXTE support mailing list to join:

`sixte-support@lists.fau.de`

NewAthena implementation

The Wide-Field Imager (WFI)

Large Detector Array (LDA) and **Fast Detector** (FD, 35 mm defocused)

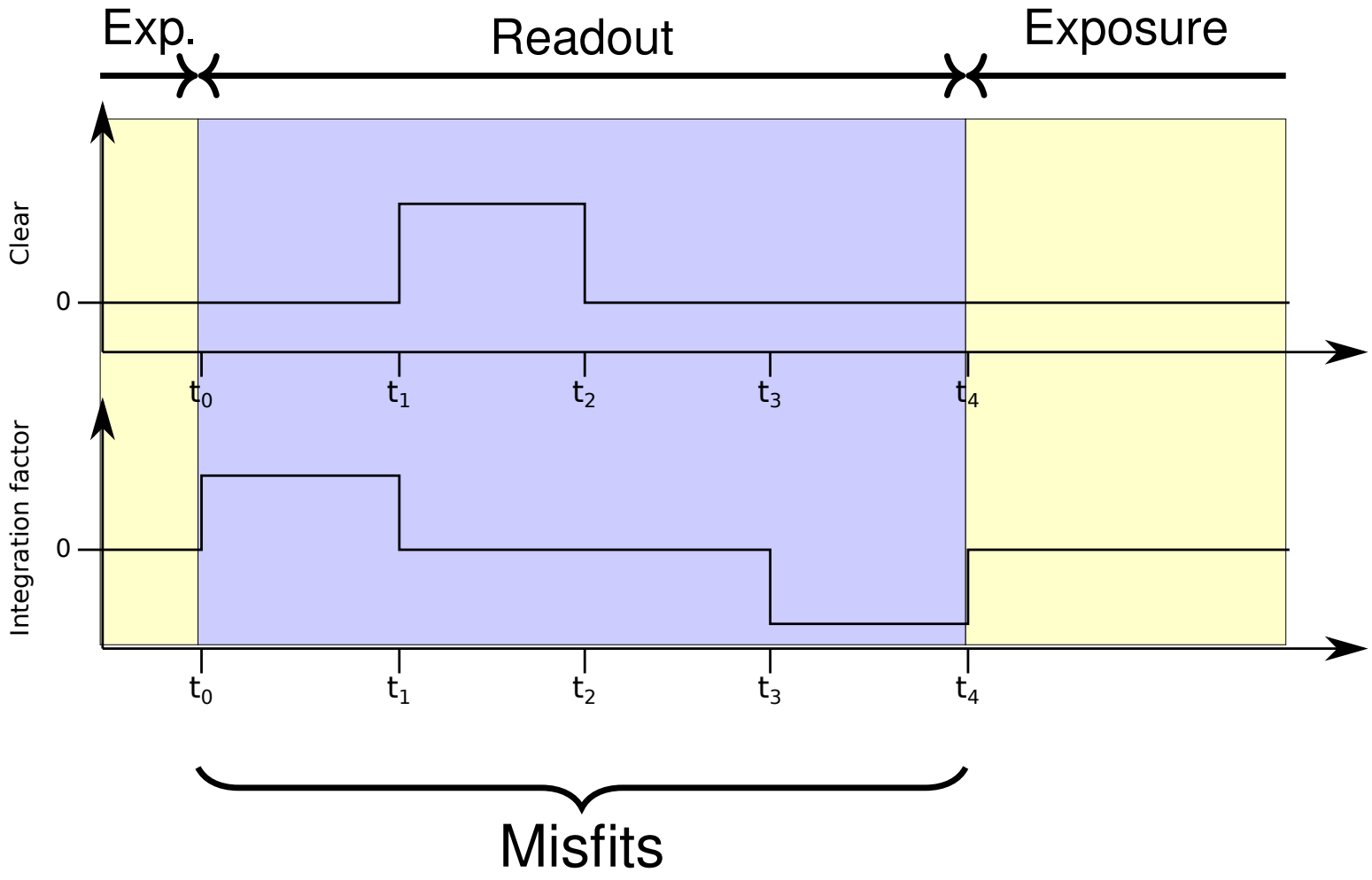


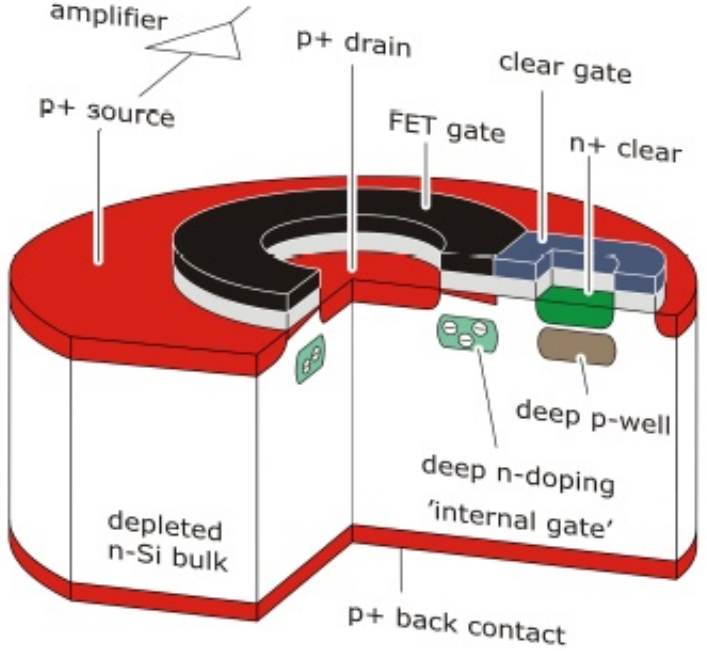
MPE

- DePFET active pixel technology
  (similar to CCD with line-by-line readout)
- Energy resolution: $\leq$ 160 eV @ 7 keV
- Large FOV: $40' \times 40'$
- High count-rate capabilities (10 Crab)

Meidinger et al. (2020)

DePFET read-out

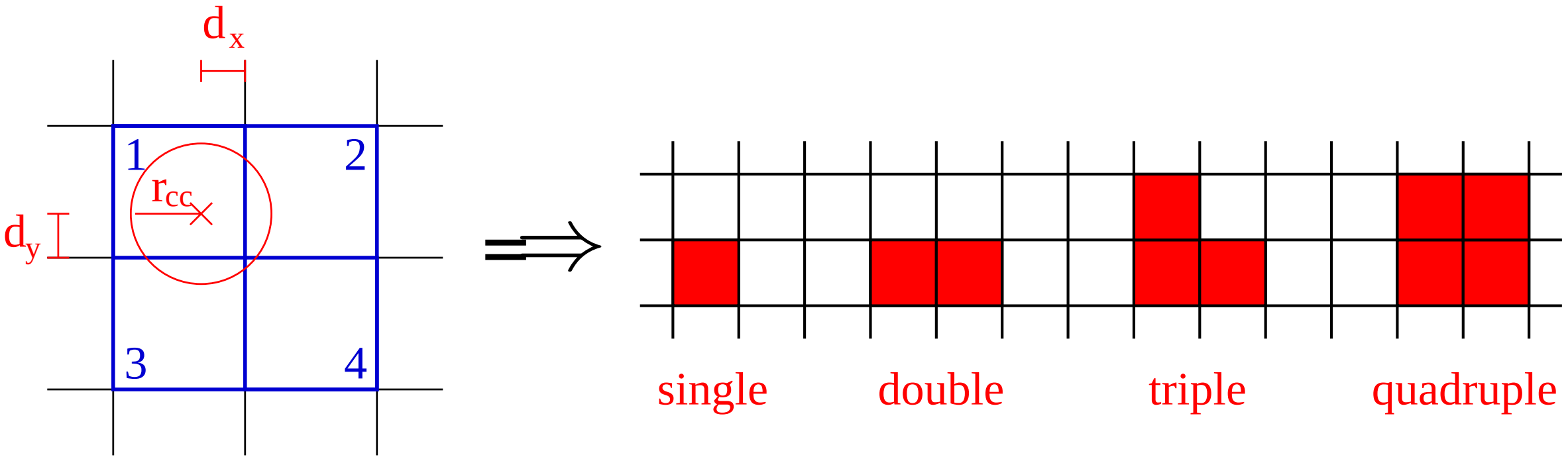




If photon hits during the read-out: measured charge is affected
$\Rightarrow$ Wrong energy (“Misfit”)

Patterns and Pileup

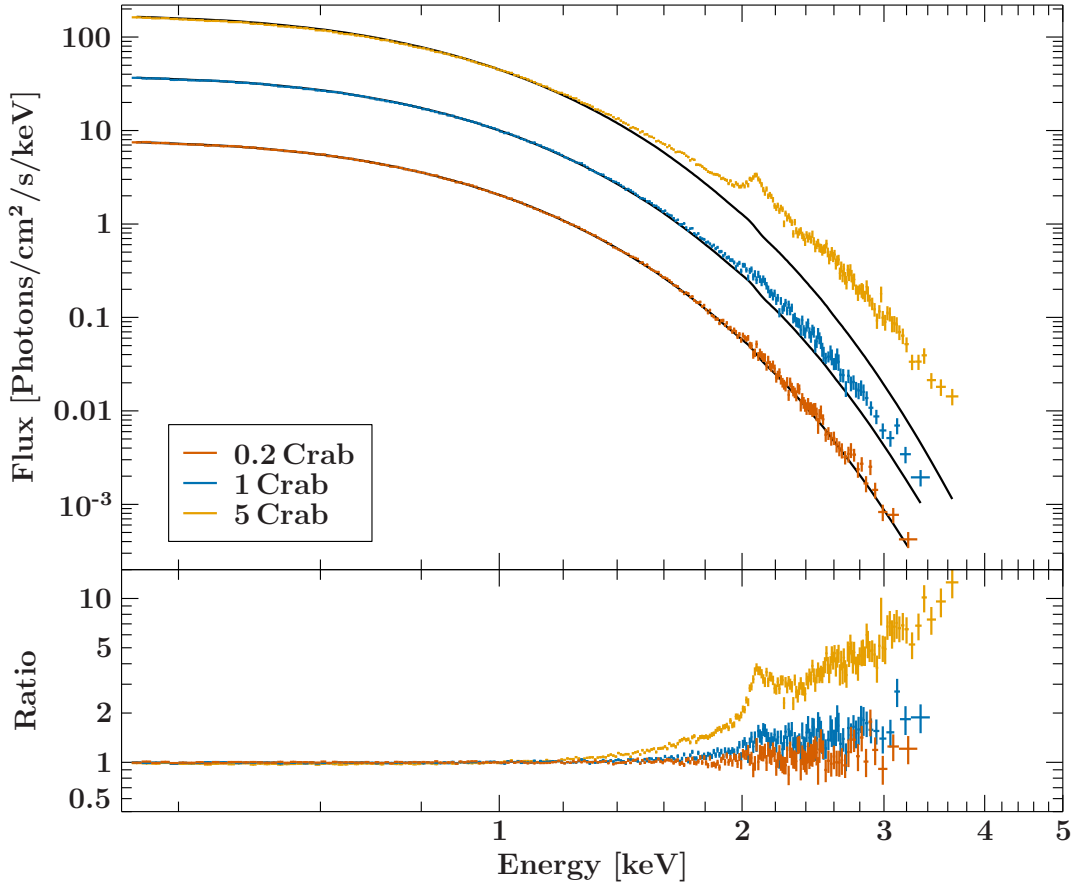
SIXTE includes charge cloud model, event patterns, and pileup.



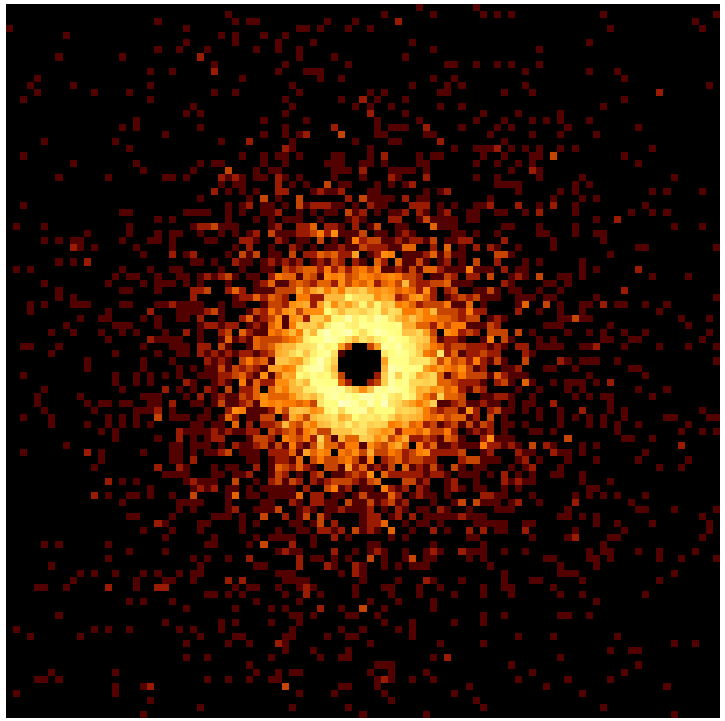
Patterns and Pileup

SIXTE includes charge cloud model, event patterns, and pileup.

Moderate pileup causes spectral distortion



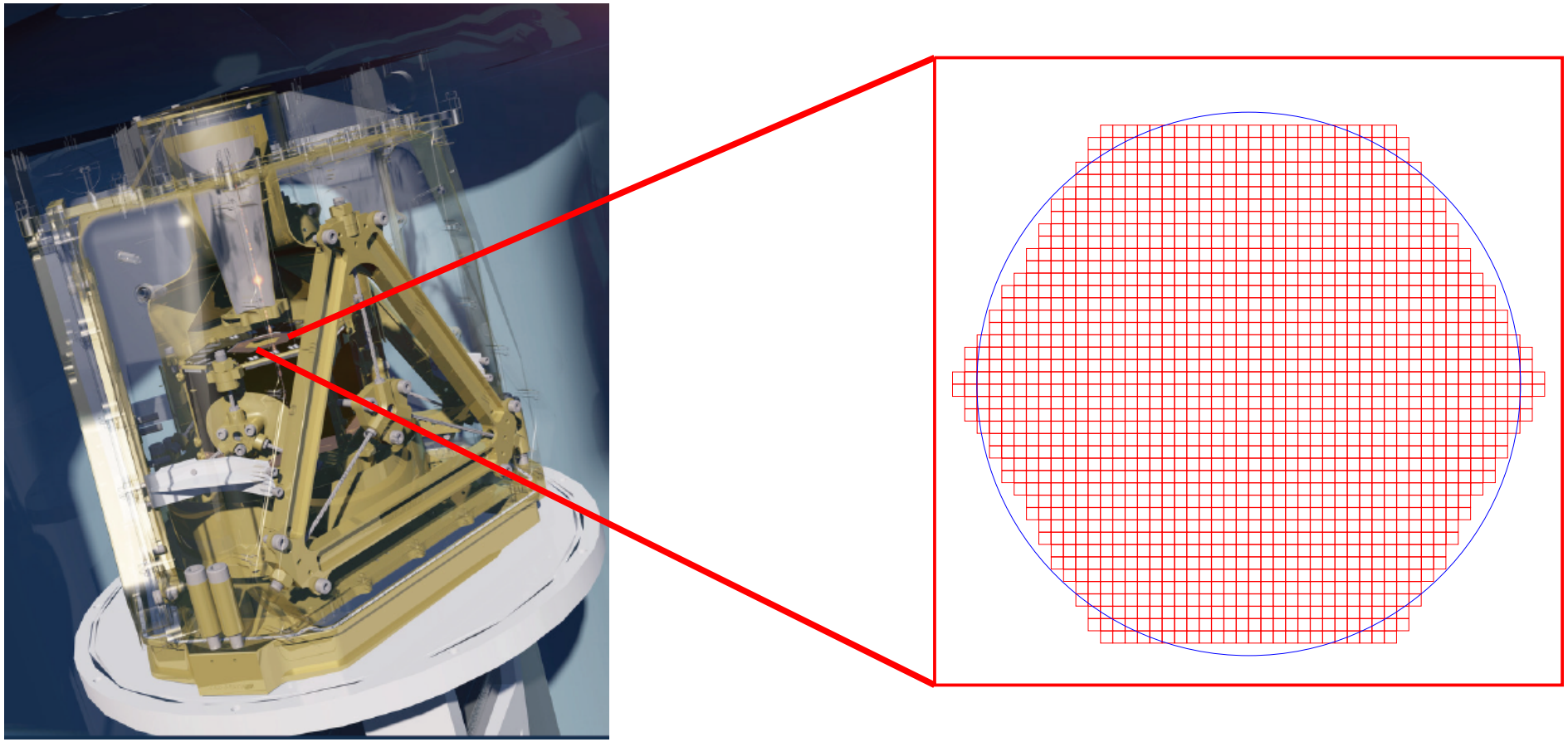
Extreme pileup causes event losses



Dauser et al. (2019)

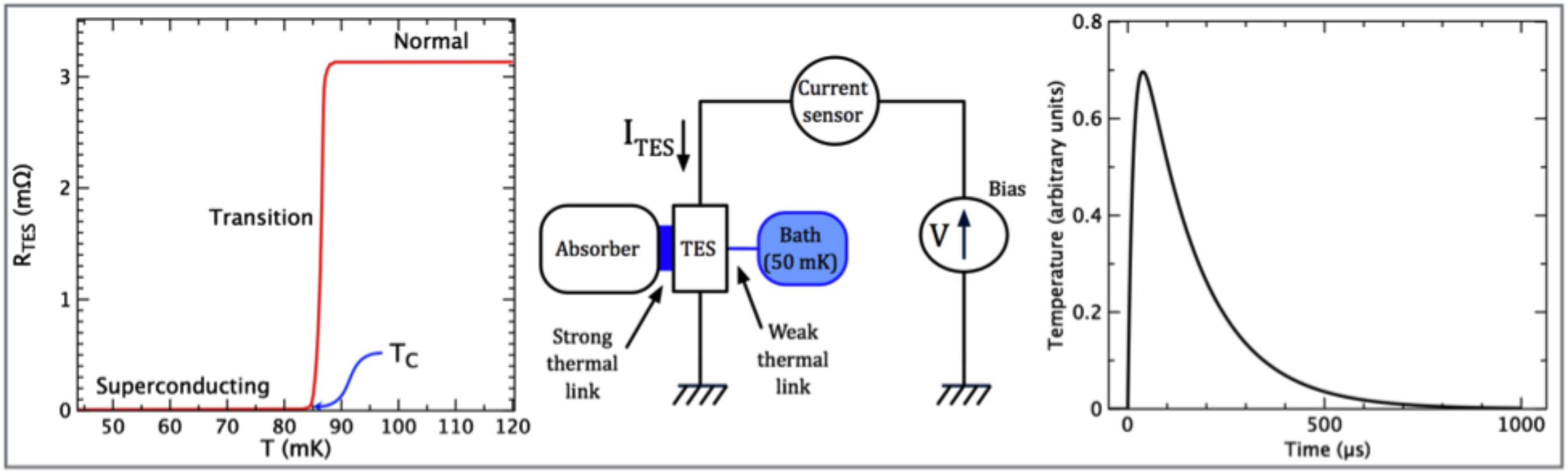
The X-ray Integral Field Unit (X-IFU)

- very high spectral resolution imaging (4 eV FWHM and a 4’ FoV)
- 1504 TES (Transition Edge Sensor) pixels

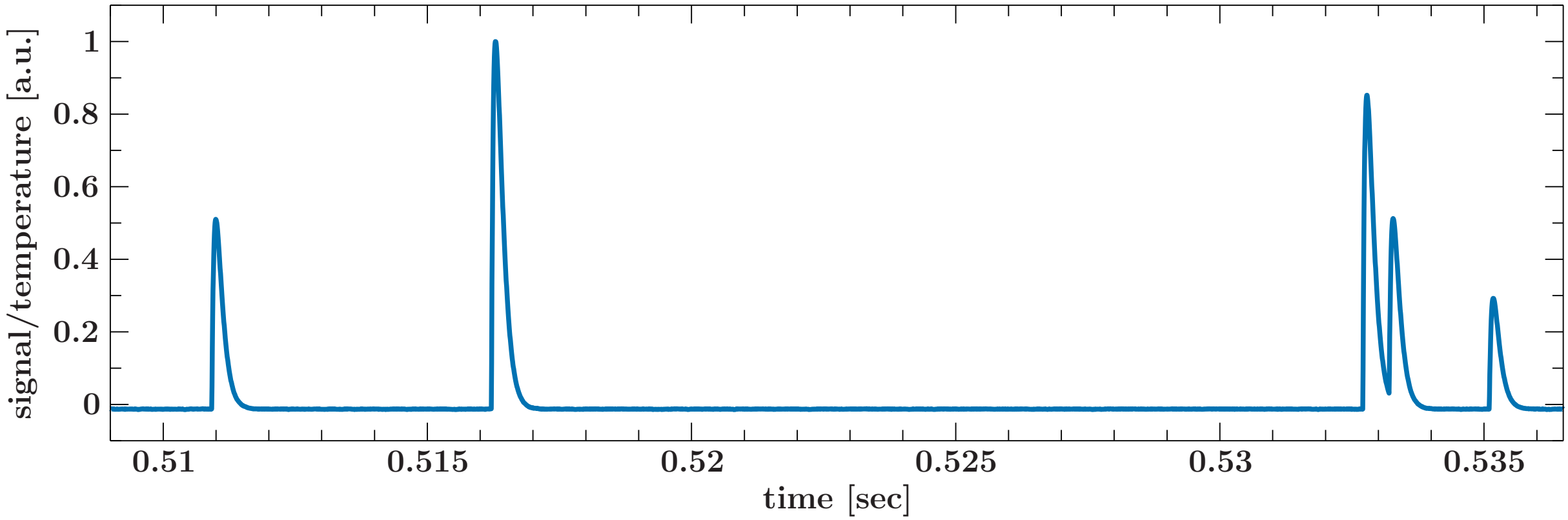


The X-ray Integral Field Unit (X-IFU)

Pixels are single *Transition Edge Sensors*, operated at 50 mK
$\Rightarrow$ **measure temperature increase** of photon hitting the pixel



Grading



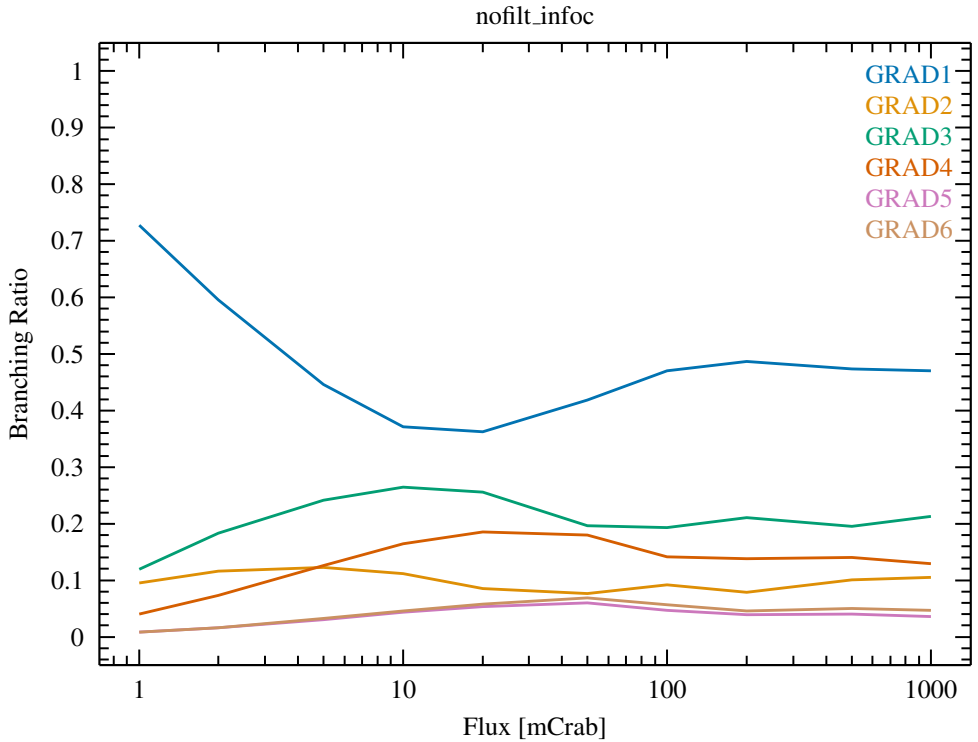
pulses with smaller separation yield lower energy resolution

$\Rightarrow$ **Event Grading** depending on the source flux

Grading

Grade	Δt since previous pulse	Δt until next pulse	Energy res.
(1) Very High res.	$\geqslant$ 24.0 ms	$\geqslant$ 55.2 ms	4 eV
(2) High res.	$\geqslant$ 24.0 ms	$\geqslant$ 26.8 ms	$\sim$ 4 eV
(3) Intermediate res.	$\geqslant$ 12.0 ms	$\geqslant$ 11.1 ms	4.2 eV
(4) Medium res.	$\geqslant$ 12.0 ms	$\geqslant$ 3.16 ms	5 eV
(5) Limited res.	$\geqslant$ 12.0 ms	$\geqslant$ 1.20 ms	7 eV
(6) Low res.	$\geqslant$ 12.0 ms	$\geqslant$ 0.05 ms	30 eV

Throughput per grade ("branching ratio") strongly depends on source flux!



Crosstalk

unintended transmission of information between signal channels

Different types of crosstalk:

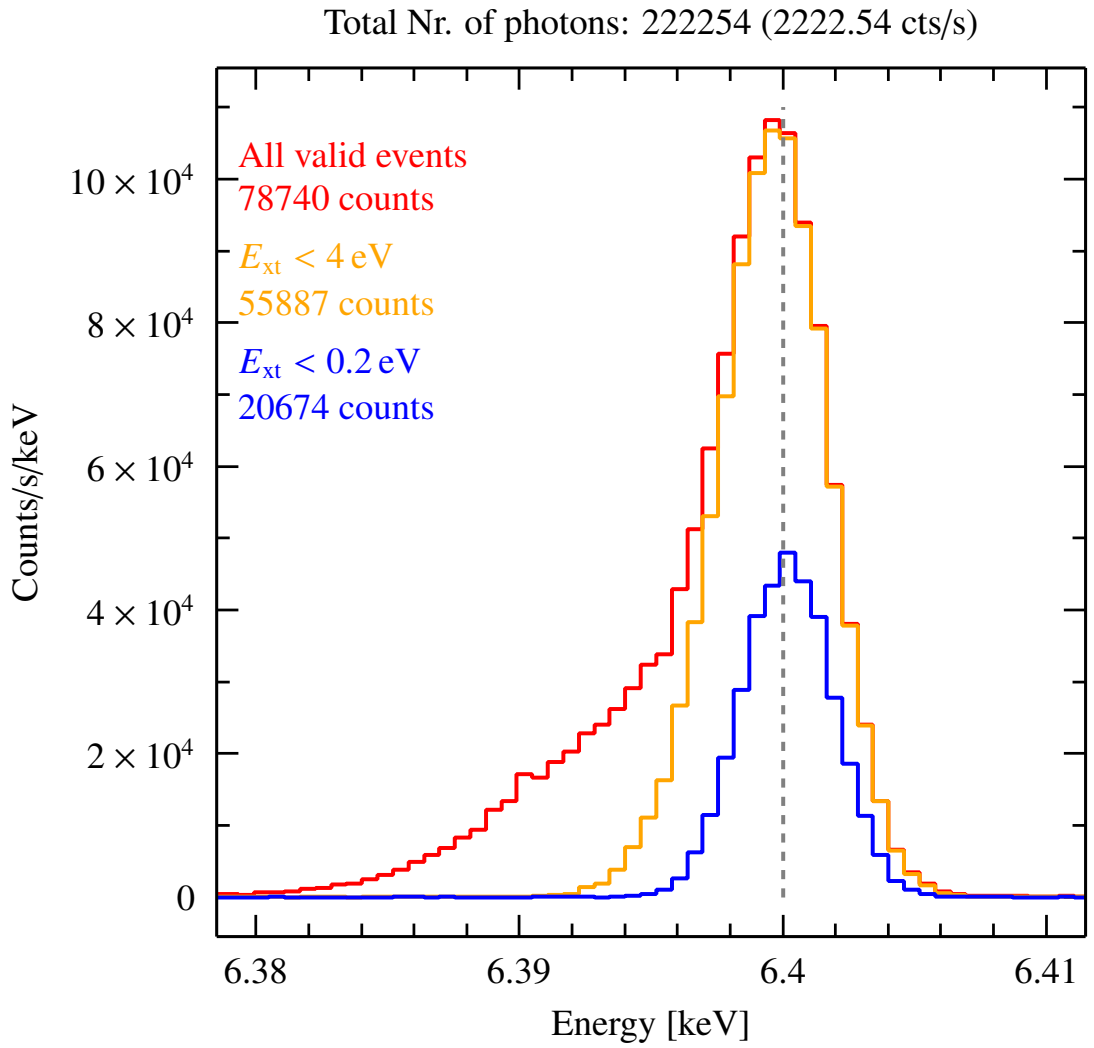
- thermal coupling of two pixels (physical neighbors)
- electrical coupling due to e.g. mutual inductance
- coupling due to multiplexed readout (TDM)

$\rightarrow$ implemented in SIXTE

crosstalk effect on events is predictable

Crosstalk

Simulation of a narrow emission line (1 Crab)



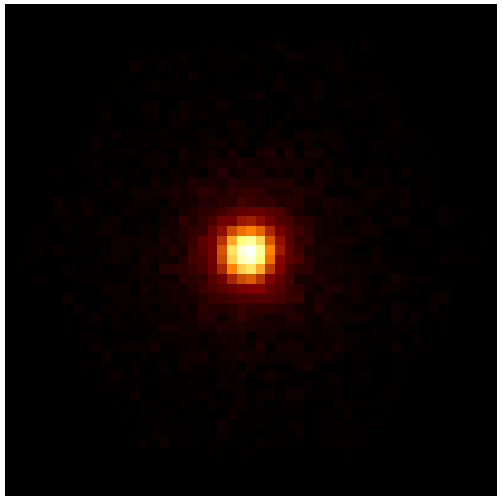
Crosstalk effect is predictable, can remove events strongly affected by crosstalk.

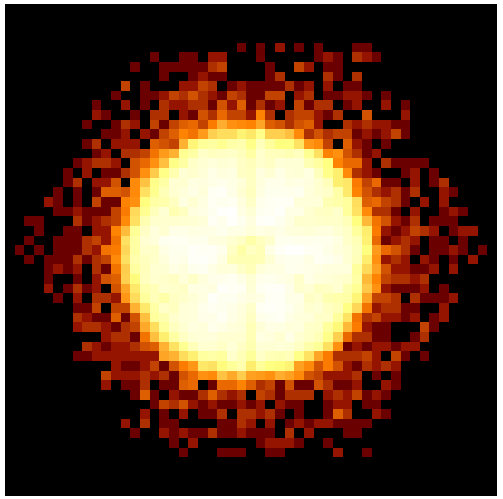
trade-off between energy resolution and throughput

Bright Source mitigation

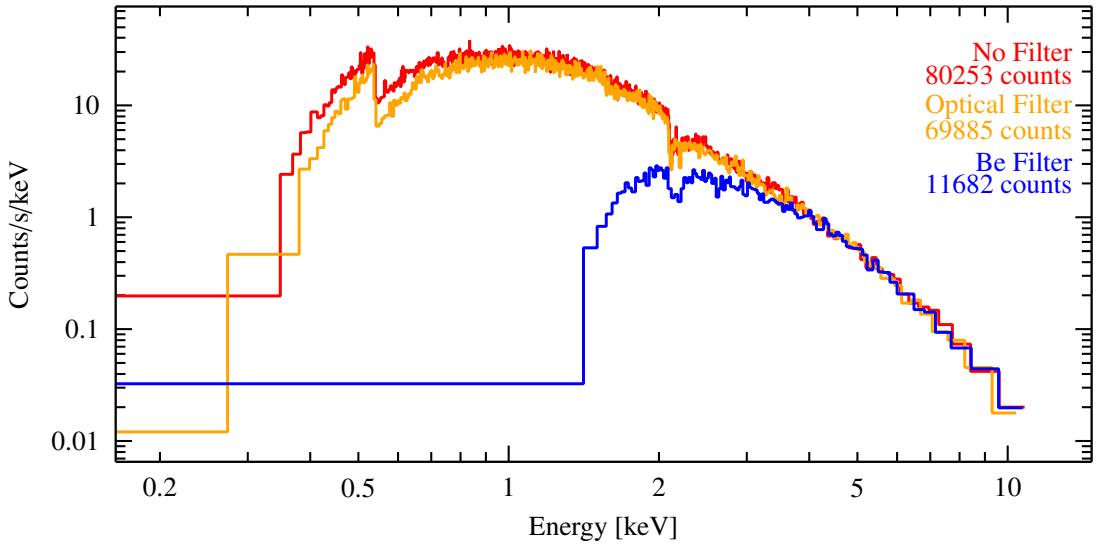
Bright source mitigation

Defocusing distributes flux across detector.





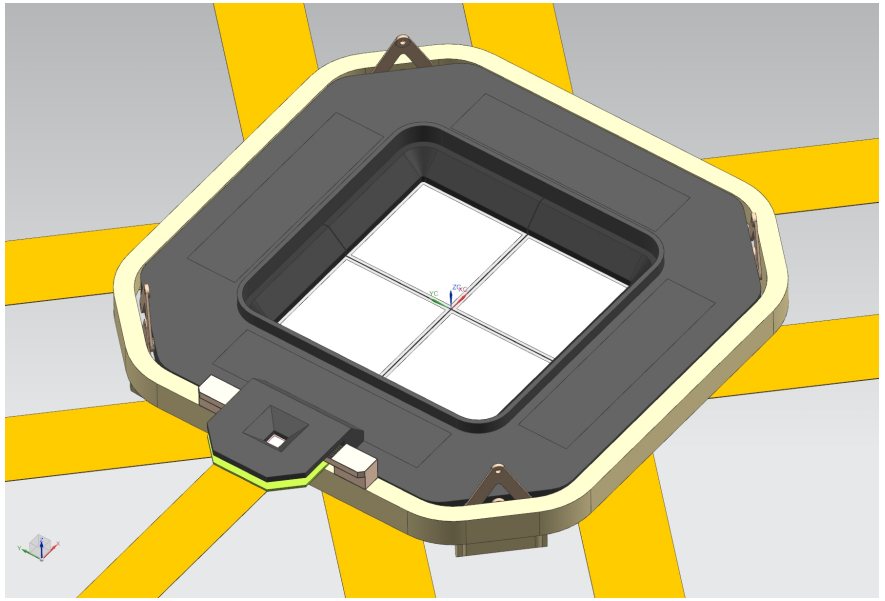
Filters reject flux at low energies.



WFI readout modes

Name	Filename	Size (rows × columns)	time resolution	defocusing	filter
full	`ld_wfi_ff_all_chips.xml`	(4×) 512 × 512	1997 μs	—	wo/w
single	`ld_wfi_ff_chip[0,1,2,3].xml`	512 × 512	1997 μs	—	wo/w
large	`ld_wfi_ff_large.xml`	512 × 512	1997 μs	—	wo/w
w128	`ld_wfi_w128.xml`	128 × 512	499 μs	—	wo/w
w256	`ld_wfi_w256.xml`	256 × 512	998 μs	—	wo/w
fast	`fd_wfi_df35mm.xml`	64 × 64	80 μs	35 mm	wo/w
fastThickFilter	`fd_wfi_df35mm_thick_filter.xml`	64 × 64	80 μs	35 mm	w

- Large Detector Array configurations available w/wo optical blocking filter.
- Fast Detector defocused by default.
- Option for a thick filter.



Compact Object simulations

Simulation Examples

Before we begin: We held a SIXTE workshop in May!

Workshop materials (recorded talks, slides, etc.) can be found here:

https://www.sternwarte.uni-erlangen.de/sixte/7th-sixte-workshop-6-7-may-2026-online/

Also includes a git repository of example simulation threads:

https://www.sternwarte.uni-erlangen.de/gitlab/sixte/public/sixte_workshop_2026

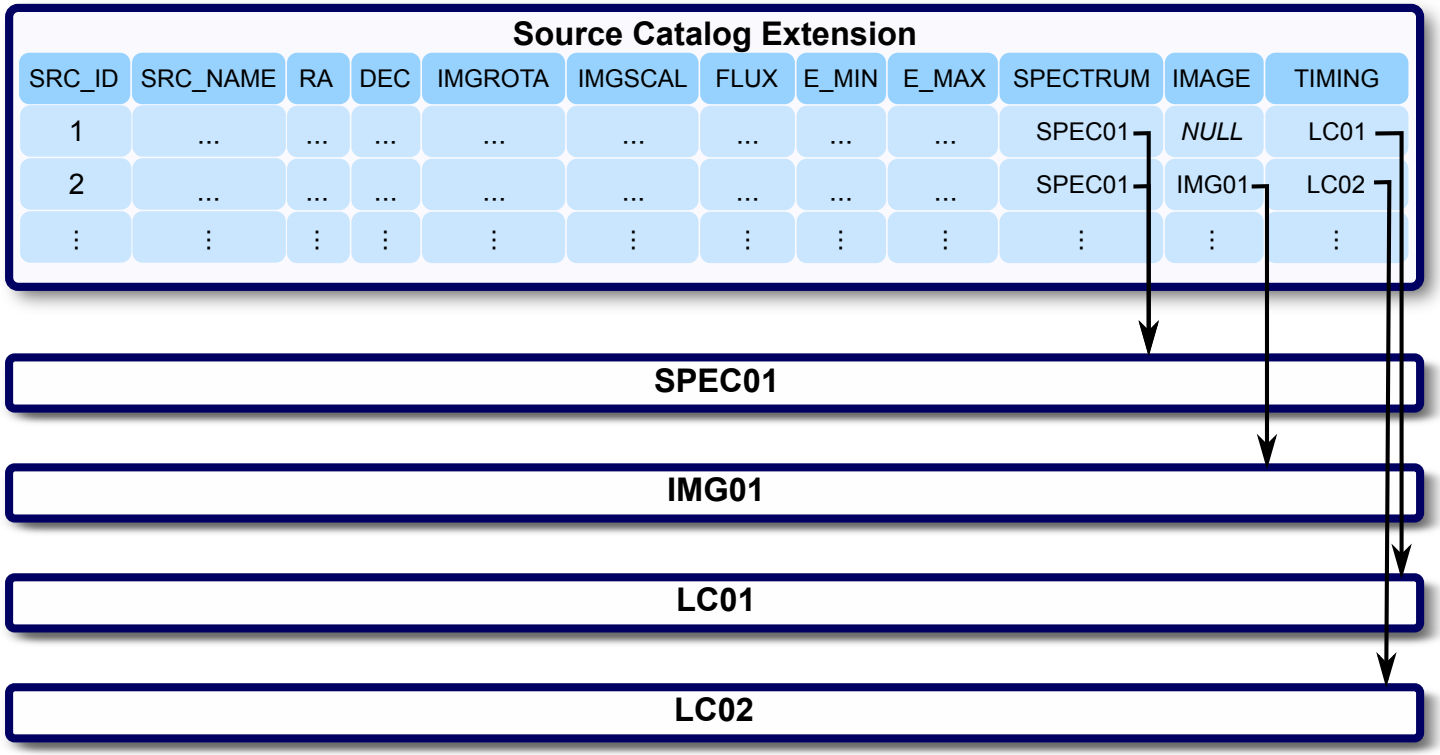
SIMPUT format

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.



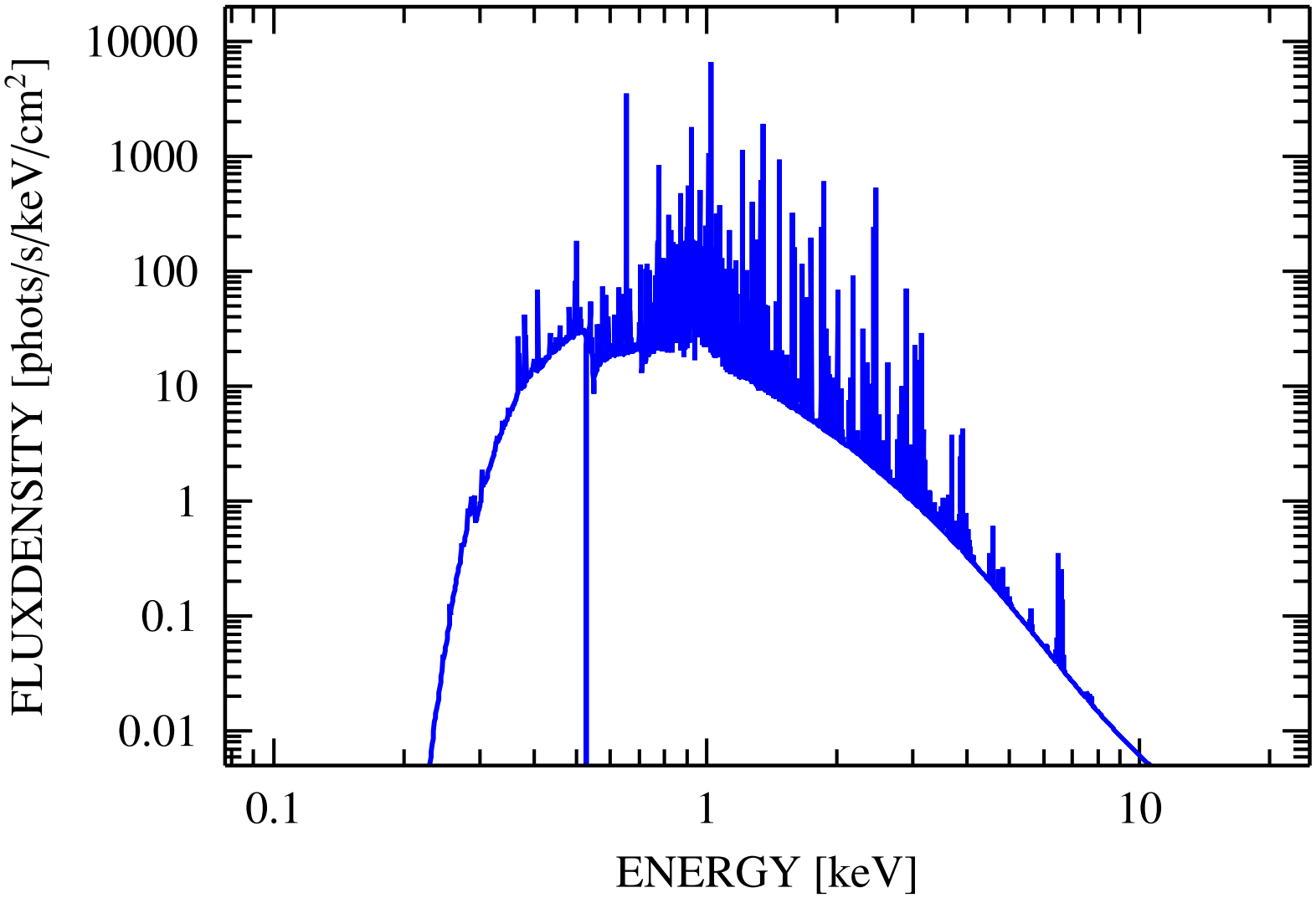
Defining a spectrum

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 - important for X-IFU!

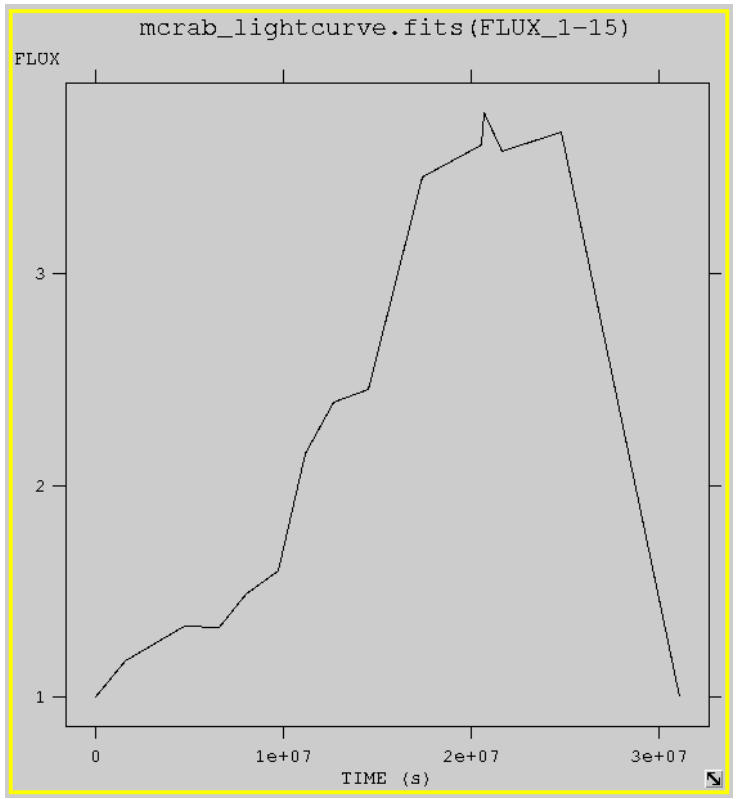


Defining variability

Variability can be defined three ways:

Aperiodic Light Curves

Flux as a function of time



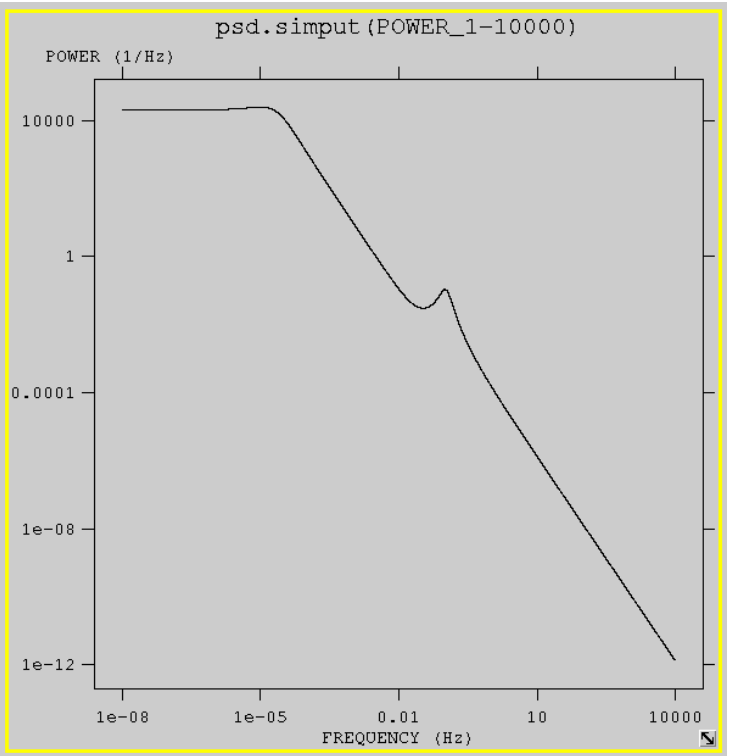
Periodic Light Curves

Flux as a function of phase, given a period

Can additionally specify $\dot{P}, \ddot{P}, \ldots, \frac{d^5 P}{dt^5}$

PSDs

Power as a function of frequency.



Many sources

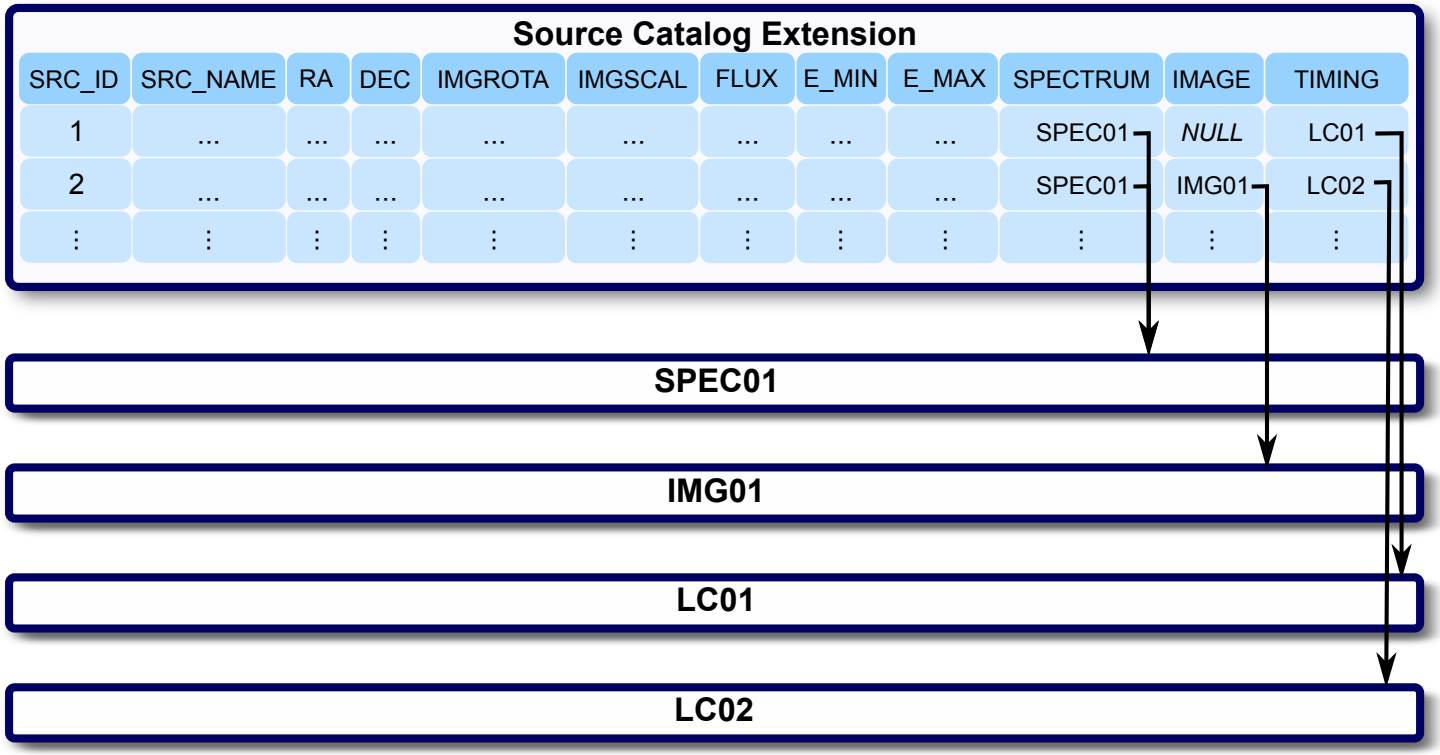
For a few sources, users can give multiple SIMPUT files as a comma separated list.

Individual SIMPUT files can also be merged into one file using the `simputmerge` tool.

This does not scale for 1e6 sources!

Remember, a SIMPUT file is a catalogue, and natively supports multiple sources.

Multiple sources can also share spectra (with independent fluxes), light curves and images (with independent scaling and rotation).



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!

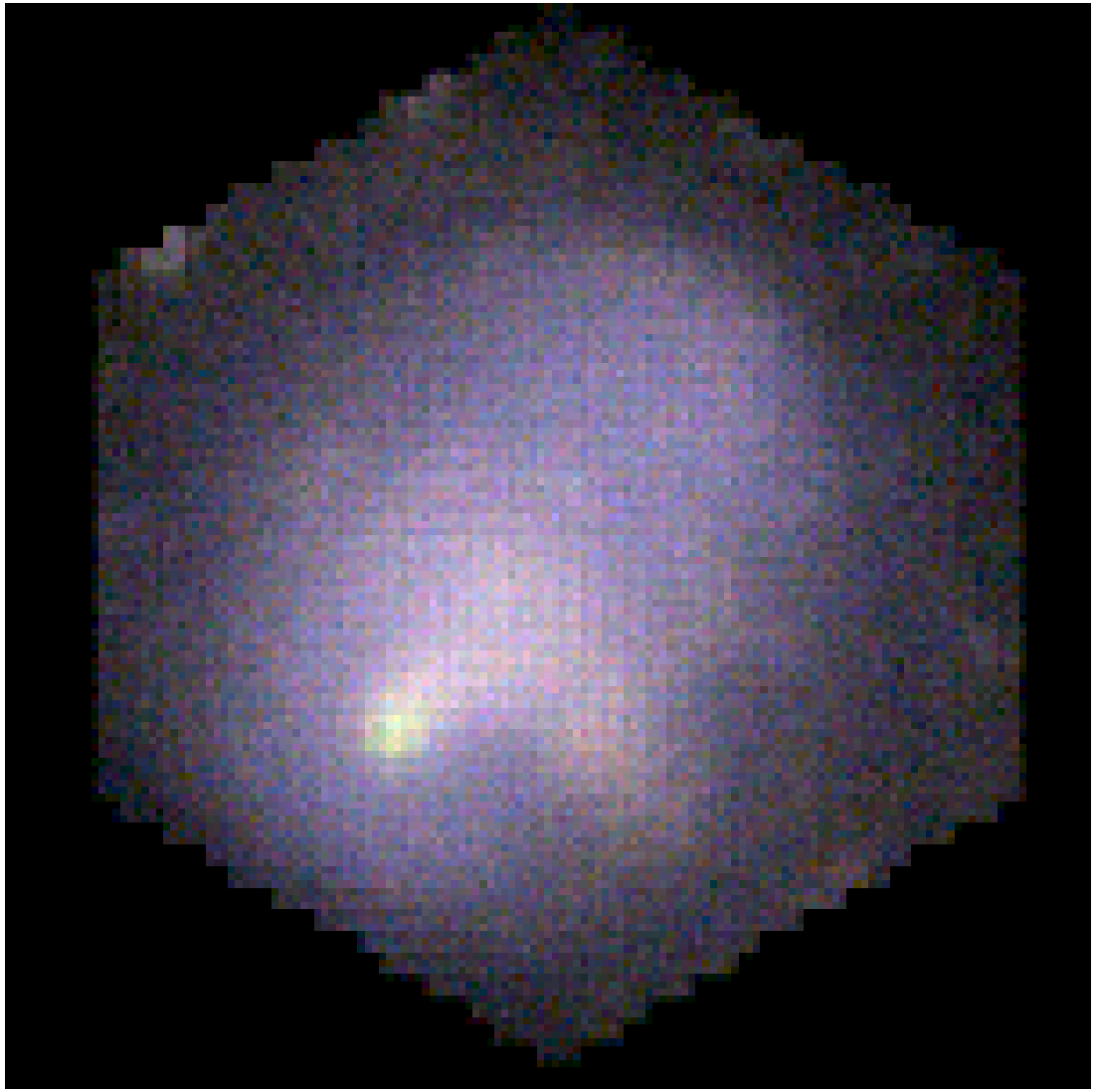
You can analyze them with anything that can read FITS!

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!

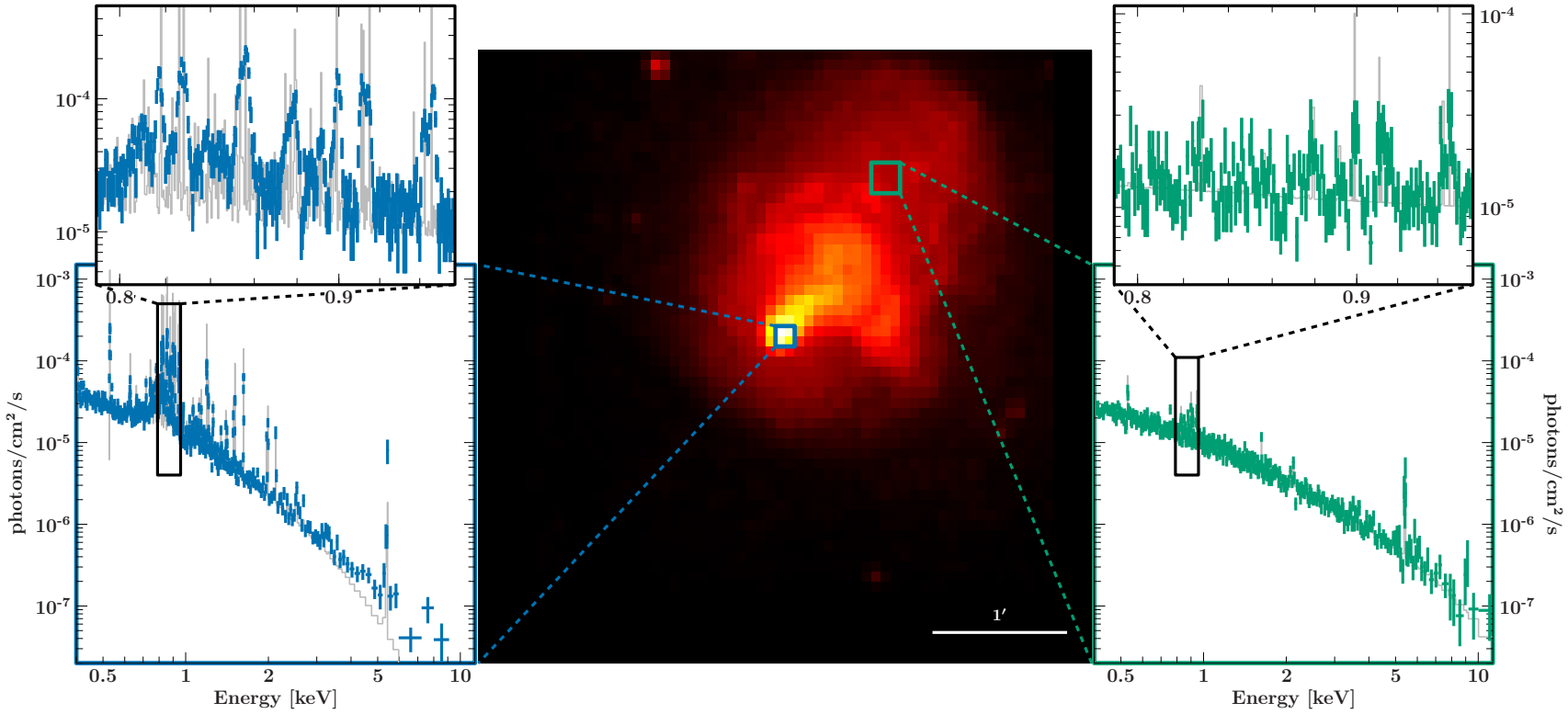


Extracting spectra

Use the `makespec` tool.

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

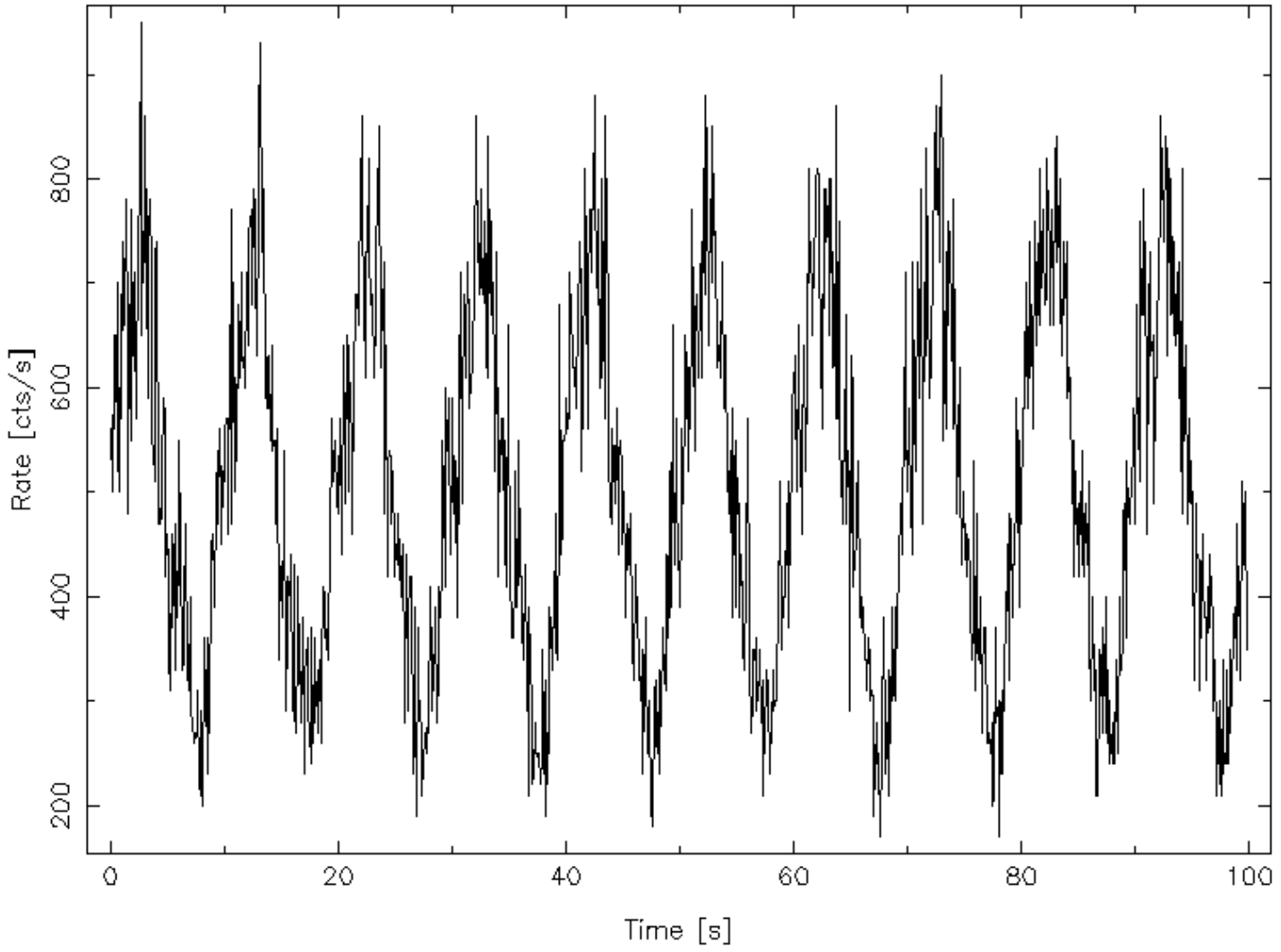
Also includes support for region and GTI files.



Extracting light curves

Use the `makelc` tool.

Can also apply GTI filtering, energy filtering, ...



Additional Information

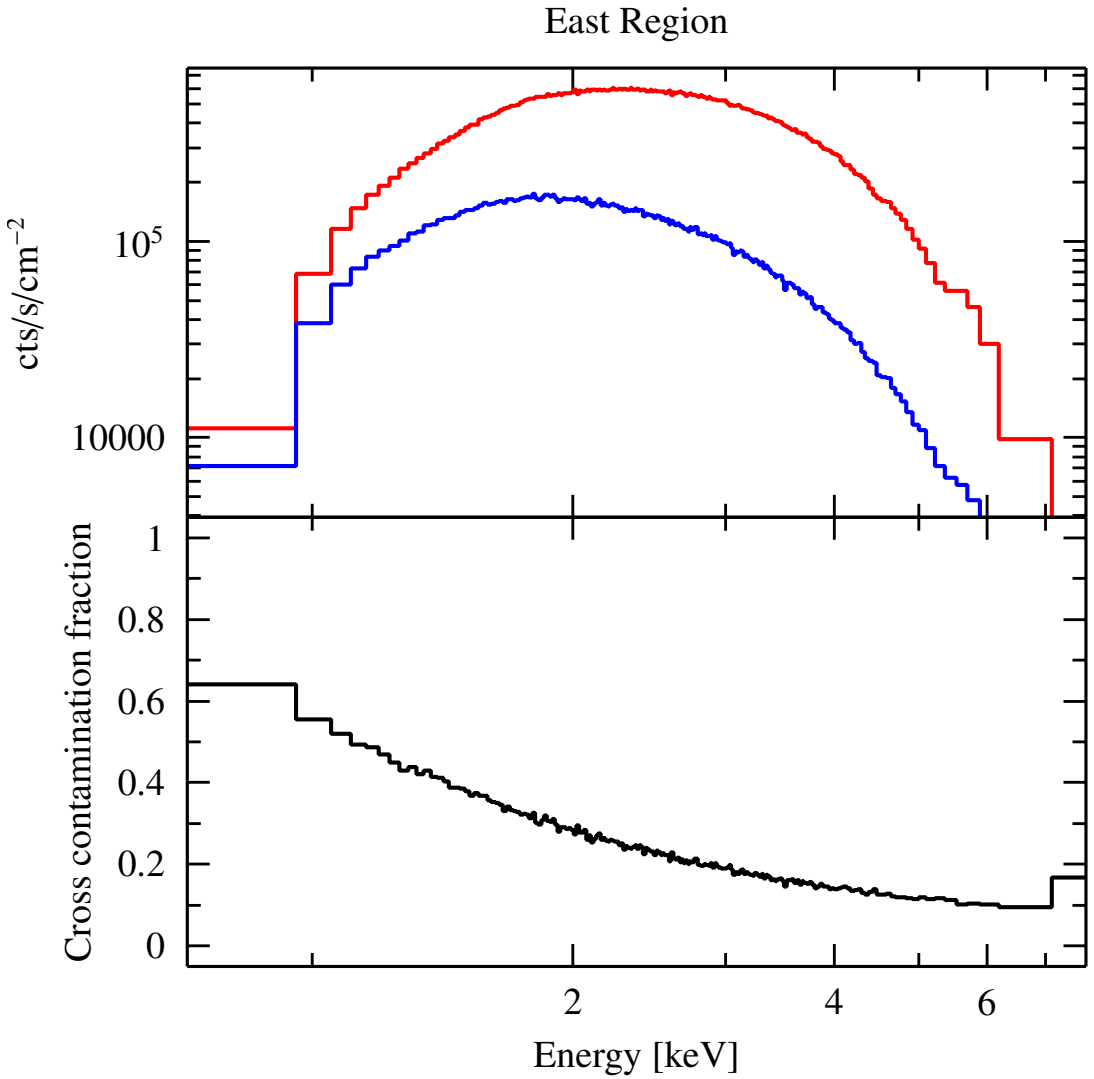
SIXTE can optionally write out some intermediate products:

- 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 regions of an extended source.



Additional Information

WFI event files contain additional information to characterize bright source effects:

- Extension columns giving the number of photons contributing to an event (PILEUP)
  - Can be used for filtering!

- Header keywords for number of valid/invalid and piled-up events (and per patttern type)

```
NVALID  =                 9485 / number of valid patterns
NPVALID =                  427 / number of piled up valid patterns
NINVALID=                 1179 / number of invalid patterns
NPINVALI=                 1179 / number of piled up invalid patterns
NGRAD0  =                 5018 / number of patterns with grade 0
NPGRA0  =                   74 / number of piled up patterns with grade 0
```

Additional Information

X-IFU event files contain additional information to characterize bright source effects:

- Extension columns giving the event grade (`GRADING`), crosstalk energy shift (`E_XT`) and number of events causing crosstalk (`N_XT`)
  - These can be used for filtering!

GRADING 1I Modify	N_XT 1I Modify	E_XT 1D keV Modify
4	1	-2.284780472218E-05
-1	0	0.000000000000E+00
-1	0	0.000000000000E+00
-1	0	0.000000000000E+00
-1	0	0.000000000000E+00
3	3	-7.209926662652E-05
4	1	-2.666993170494E-05
-1	0	0.000000000000E+00
3	0	0.000000000000E+00
1	11	-1.414753001797E-03
1	7	-1.828143950962E-04
1	2	-1.836882067134E-04
1	9	1.142133631182E-04
1	16	-1.324613853145E-03
1	4	-6.917426857100E-05
1	0	0.000000000000E+00
3	2	1.652283974995E-03
5	1	-6.102067764273E-04
-1	0	0.000000000000E+00
3	5	1.800124248924E-03

- Header keywords for number of valid/invalid events and overall grade distributions

```
NEVT    =                222791 / number of events simulated
NVALID  =                160569 / number of events with valid grades
NINVALID=                 62222 / number of events with invalid grades
NGRAD1  =                 91267 / number of events with grade 1
NGRAD2  =                 14152 / number of events with grade 2
NGRAD3  =                 28479 / number of events with grade 3
NGRAD4  =                 17220 / number of events with grade 4
NGRAD5  =                  4602 / number of events with grade 5
NGRAD6  =                  4849 / number of events with grade 6
```

Summary

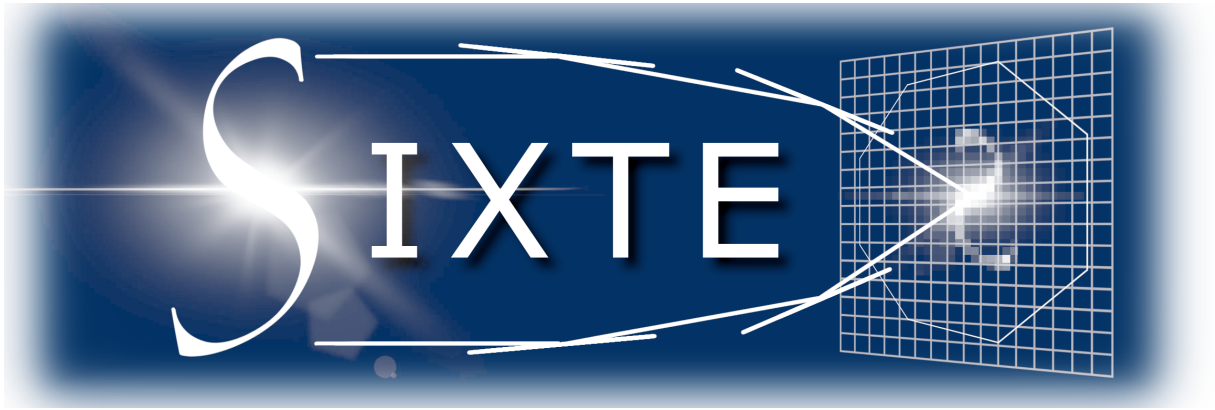
Most complex part of SIXTE simulations is **generating the SIMPUT**

For certain approaches, we already have existing tools.

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

When analyzing data, especially spectra, **consider readout effects of e.g. bright sources**

NewAthena event files have statistics on pileup/grading, number of lost events. . .



Thank you for your attention!