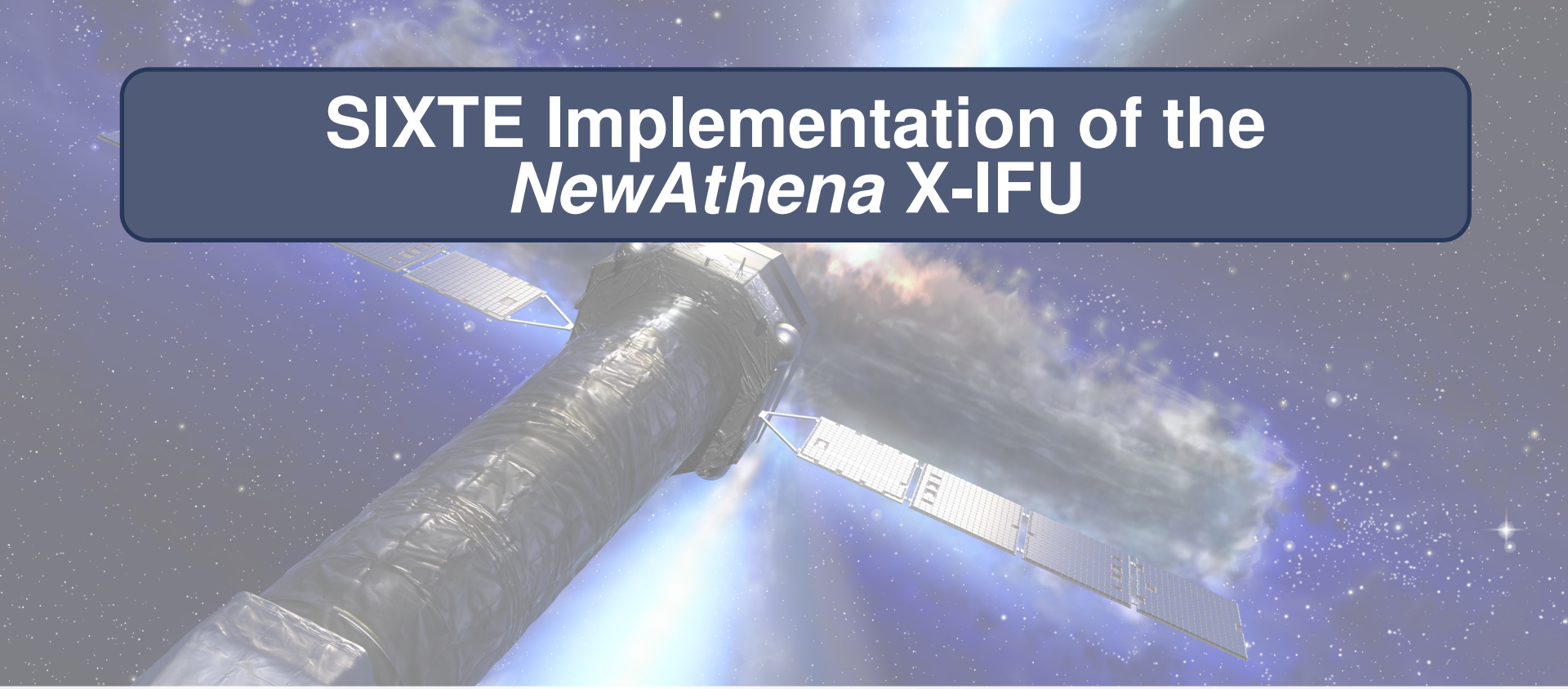
SIXTE Implementation of the *NewAthena* X-IFU



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Remeis Observatory & ECAP

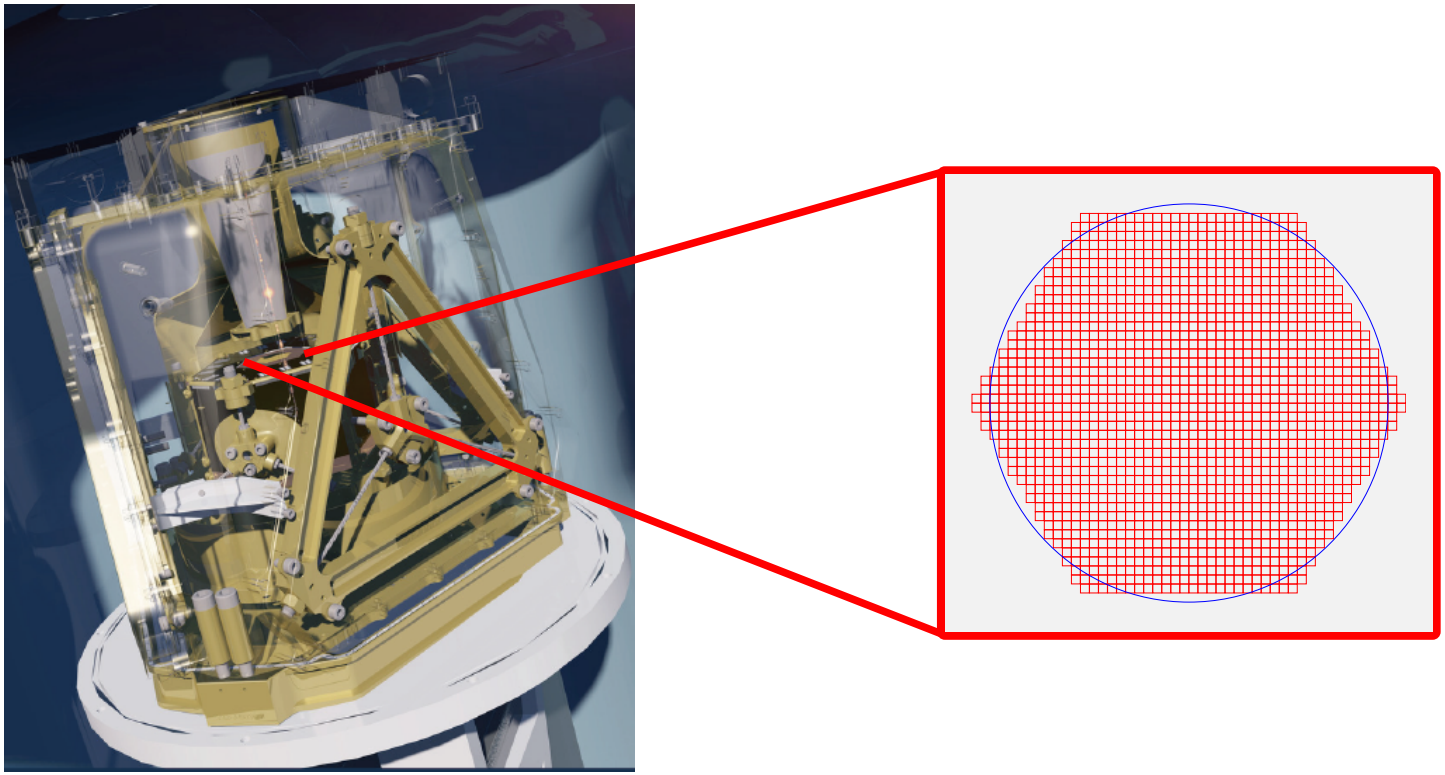
SIXTE Workshop — May 2026

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

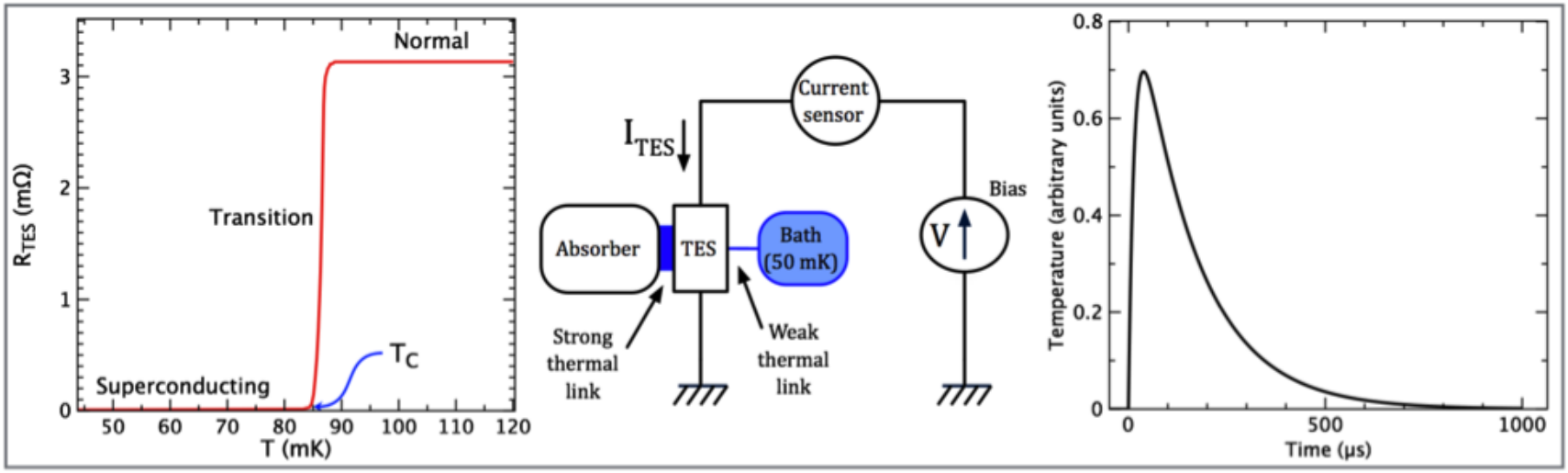
The X-ray Integral Field Unit (X-IFU)

- 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



X-IFU Implementation in the end-to-end simulator SIXTE

`sixtesim`:

- full detector array
- full imaging implemented
- fast detection simulation using response matrices + microcalorimeter-specific effects

$\Rightarrow$ **science simulations**

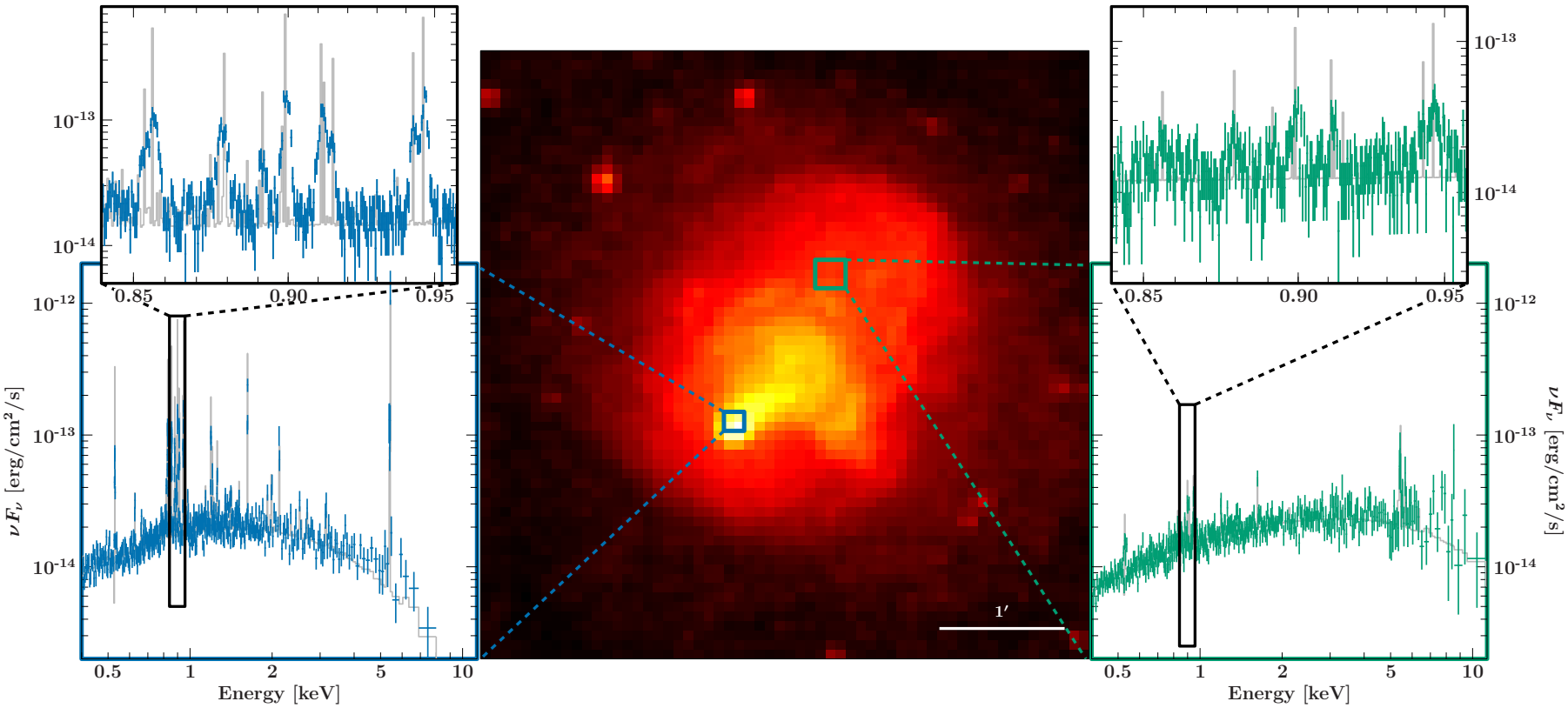
`tessim/xifusim` + SIRENA

- Simulation of TES physics and pulse reconstruction
- Slower than `sixtesim`, but much better physics
- pixel interaction (crosstalk)

$\Rightarrow$ **Input for** `sixtesim`

$\Rightarrow$ **physics-based** `tessim/xifusim` **results converted to be used in the fast and general** `sixtesim` **simulation (event grading, crosstalk, . . .)**

Example: SIXTE X-IFU simulation of a Galaxy Cluster

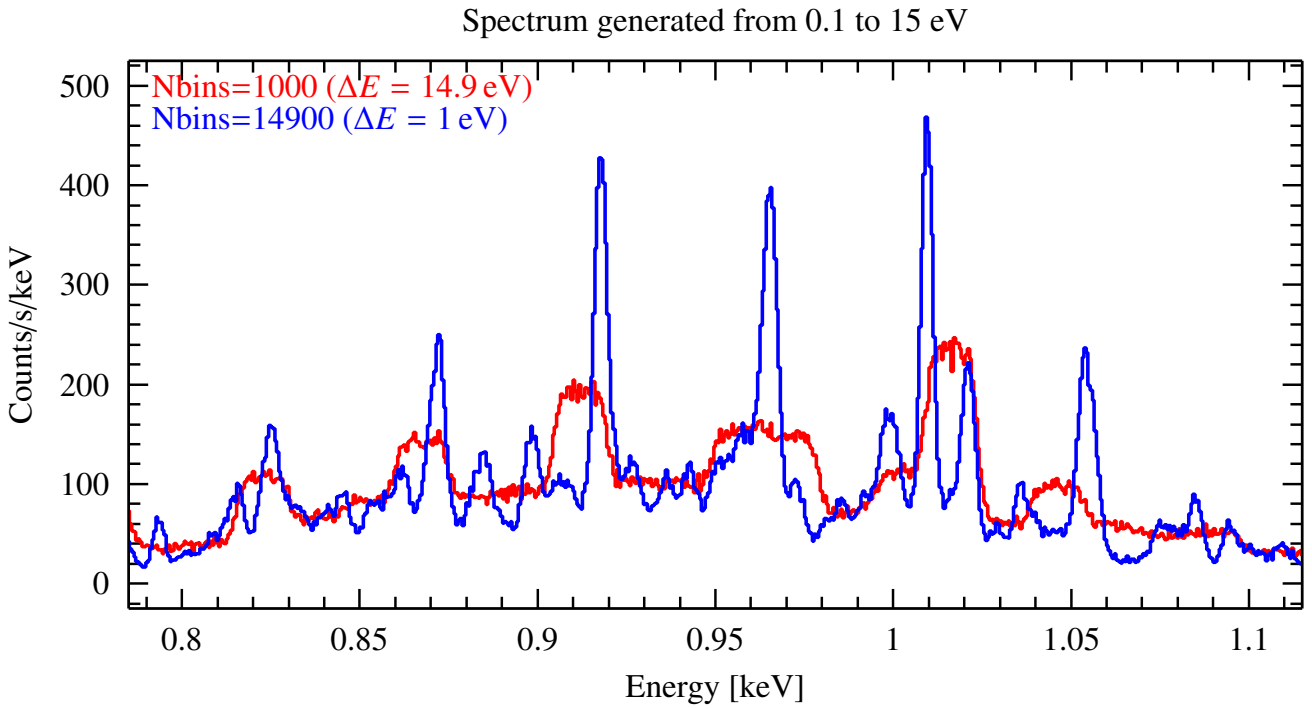


SIXTE describing, simulating, and analyzing complicated sources

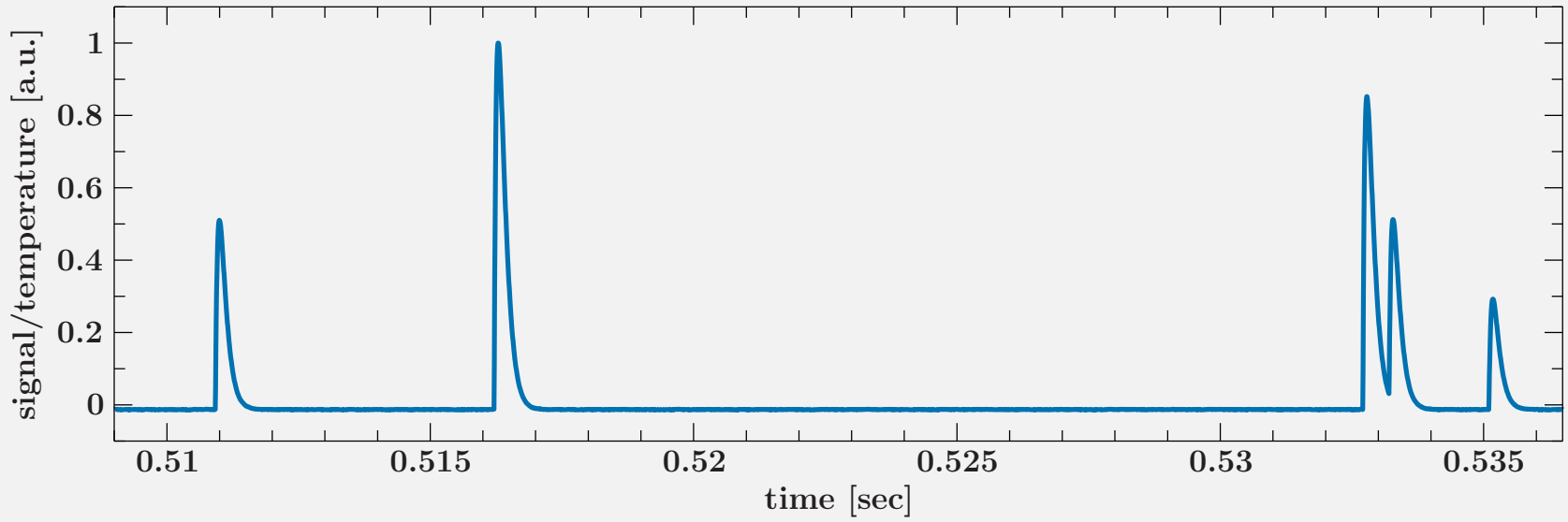
X-IFU spatially resolved high-resolution spectroscopy

Simput Binning

One consideration for any high-resolution instrument: binning your SIMPUT!
When calling `simputfile` with an XSPEC or ISIS file, the spectrum is evaluated once, on the energy grid defined by the parameters `Elow`, `Eup` and `Nbins`.
Setting this value too low will have strange effects on a spectrum with high-resolution features (e.g. an APEC):



Grading



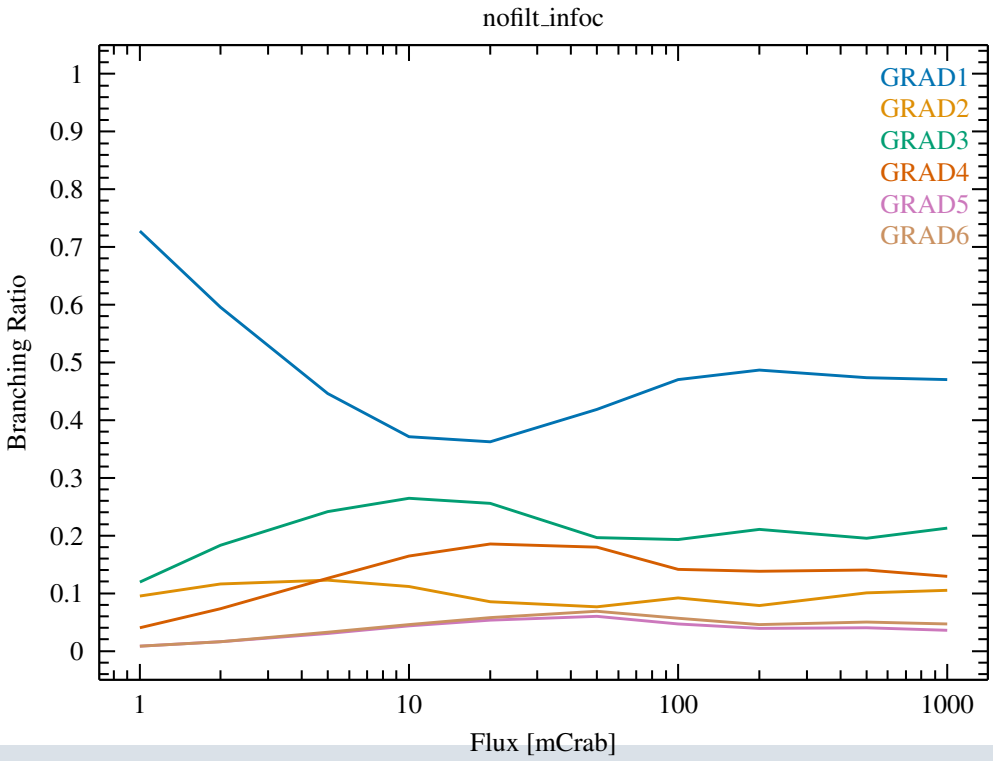
pulses with smaller separation yield lower energy resolution

$\Rightarrow$ **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:

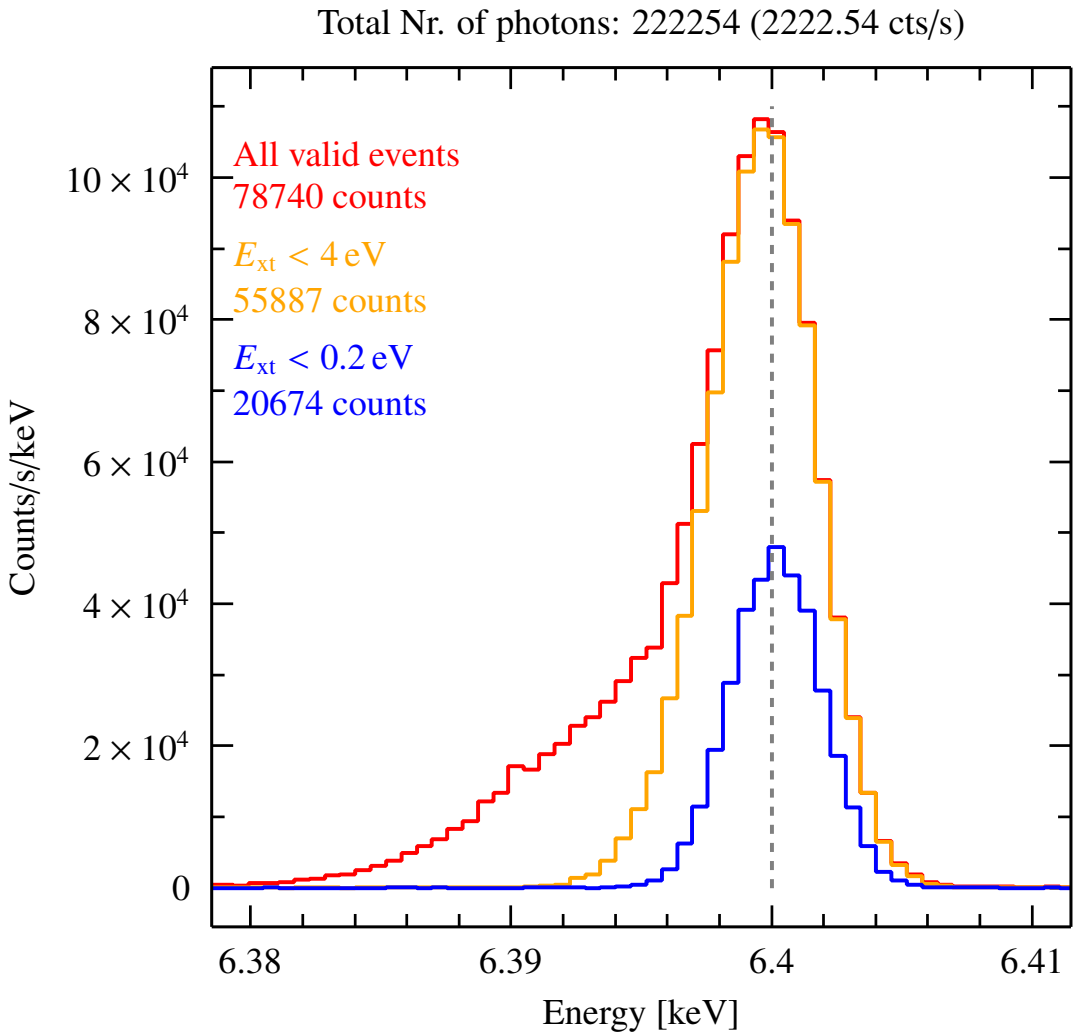
- thermal coupling of two pixels (physical neighbors)
- electrical coupling due to e.g. mutual inductance
- coupling due to multiplexed readout (TDM)

$\rightarrow$ implemented in SIXTE

crosstalk effect on events is predictable

Crosstalk

Simulation of a narrow emission line (1 Crab)

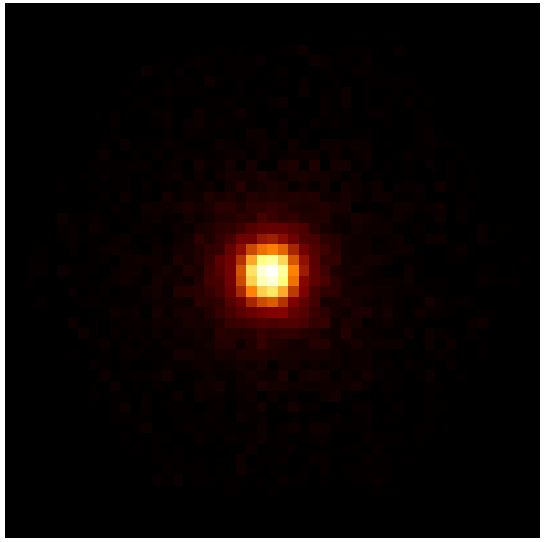


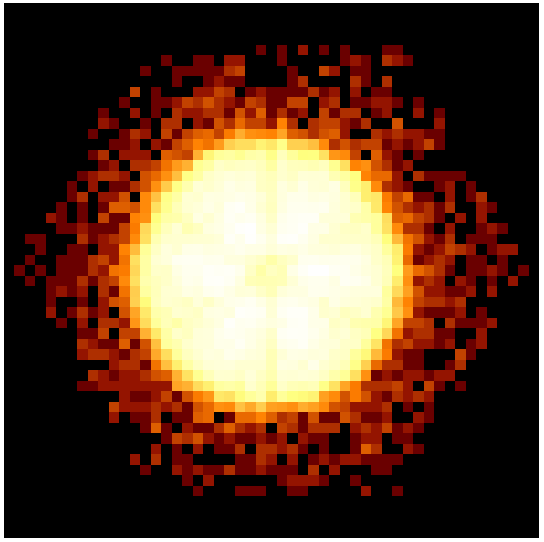
Crosstalk effect is predictable, can remove events strongly affected by crosstalk.

trade-off between energy resolution and throughput

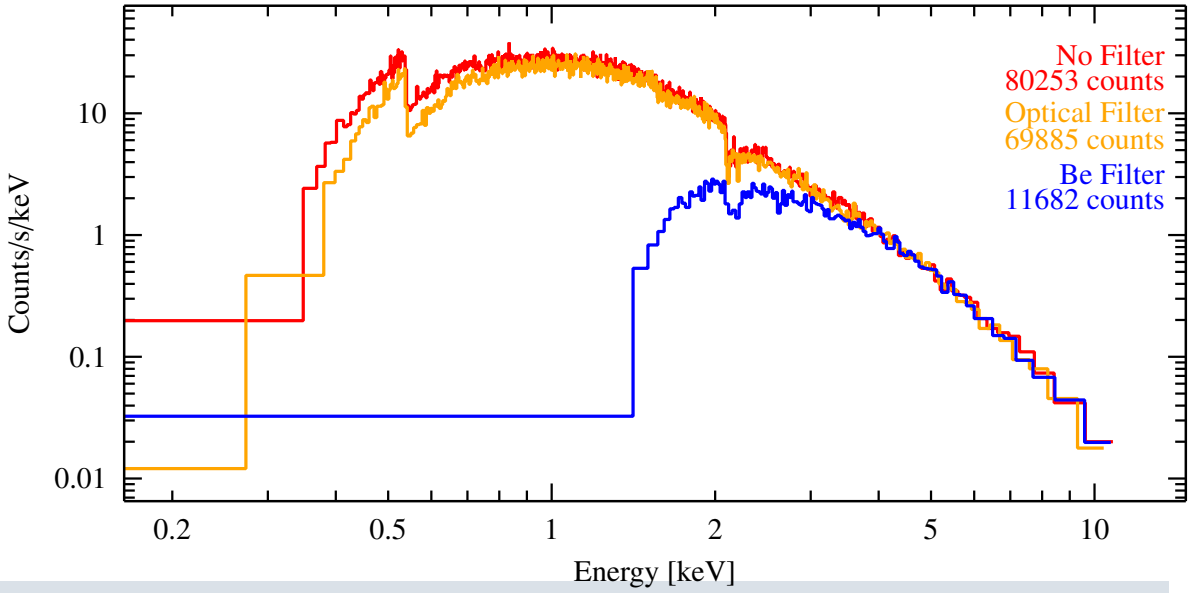
Bright source mitigation

Defocusing distributes flux across detector.



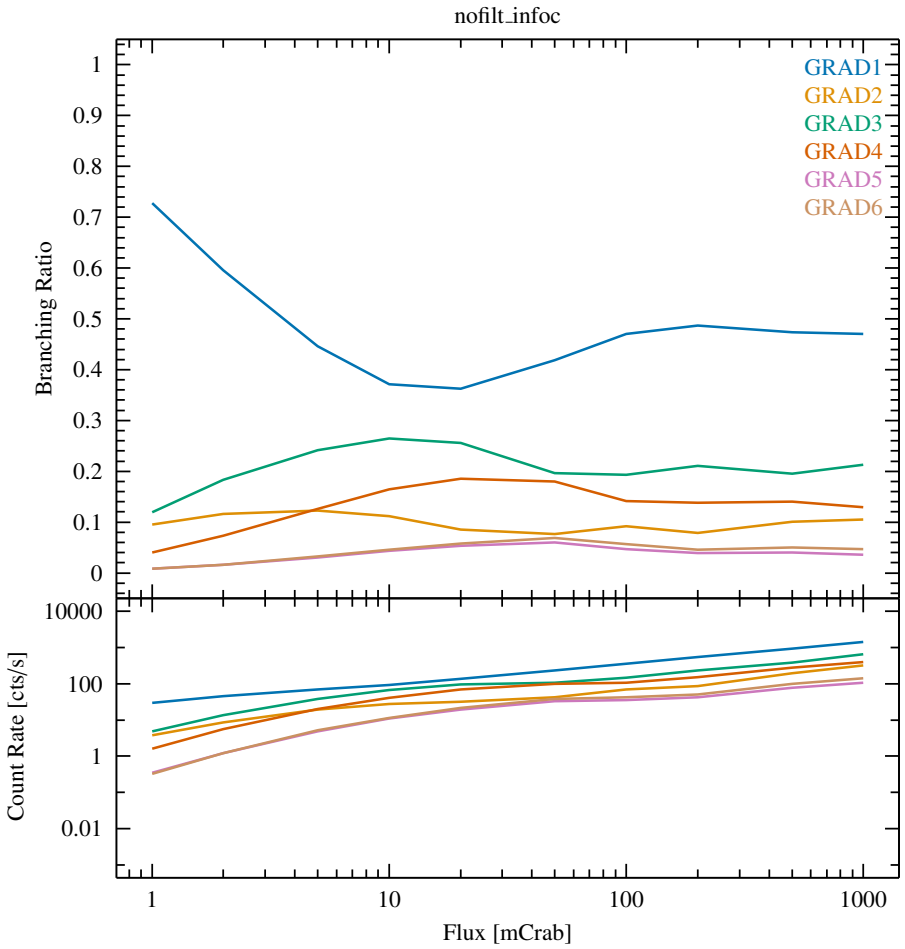


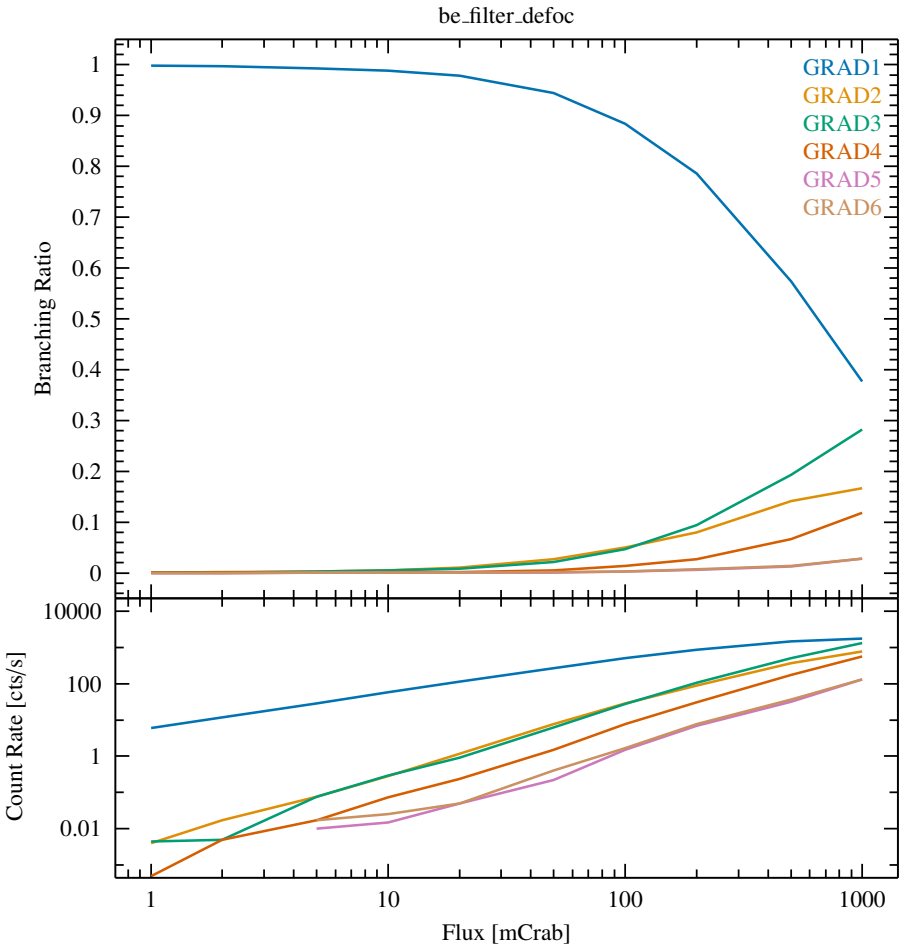
Filters reject flux at low energies



Bright source mitigation

Use defocusing + filter to improve high-resolution throughput

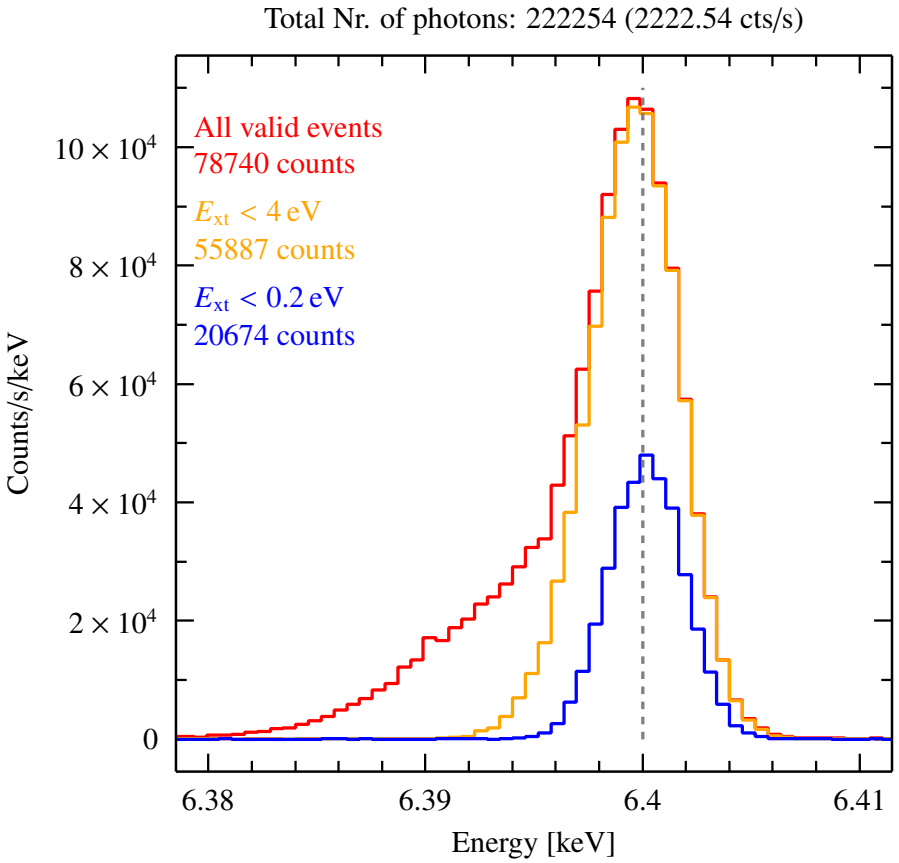




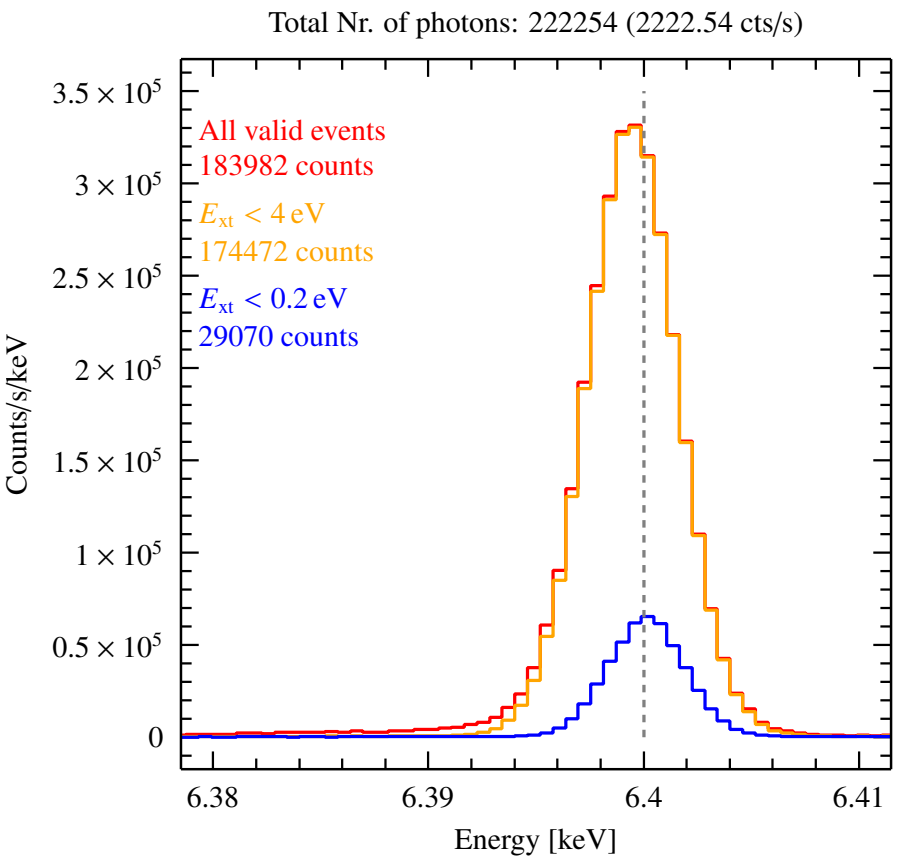
Bright source mitigation

Use defocusing to improve number of valid events and crosstalk performance

In-Focus



Defocused



Bright source mitigation

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
```

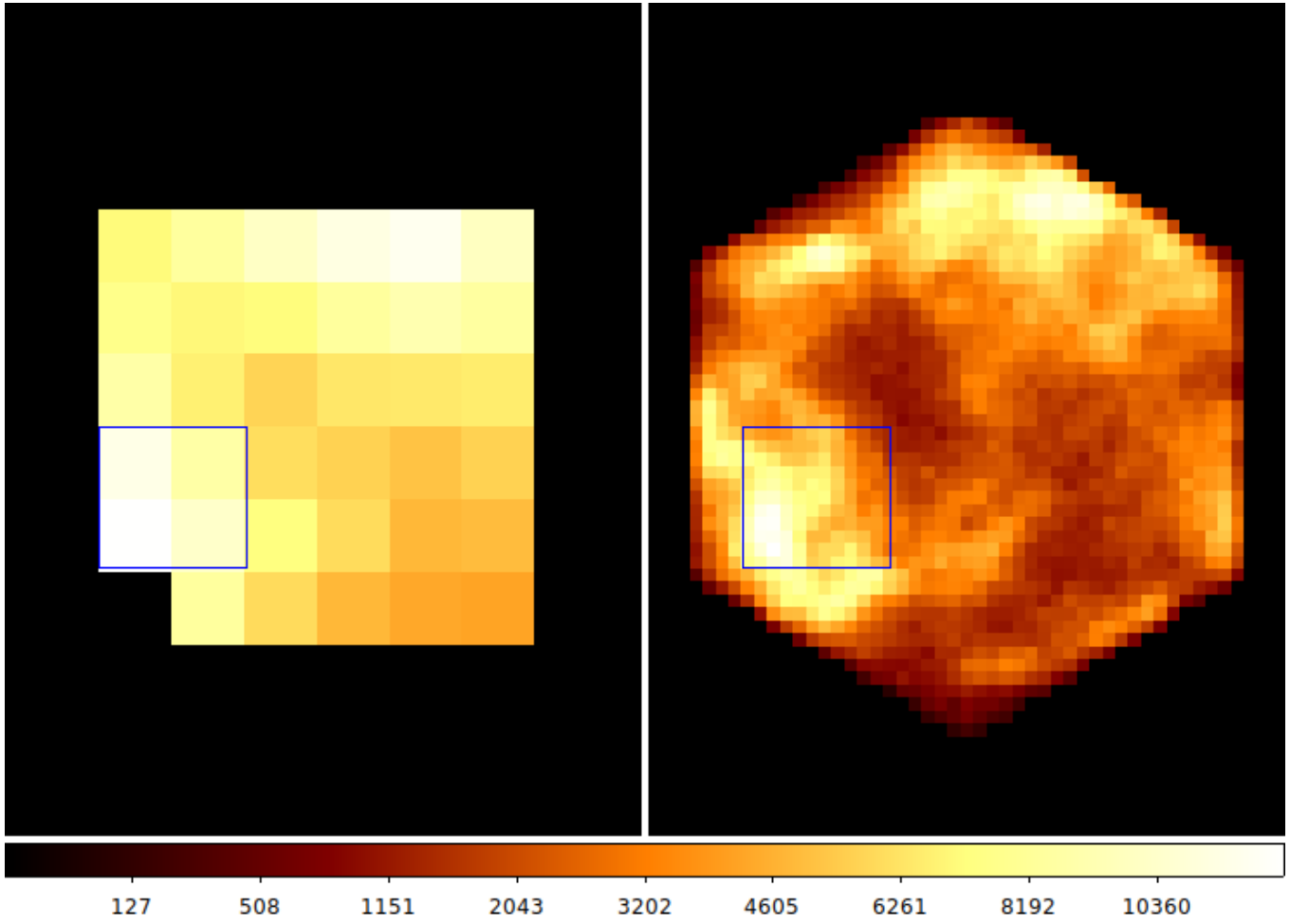
XRISM Resolve

How do we simulate XRISM Resolve with SIXTE?

Simply use `sixtesim` with a different XML!

This simulates the Grading effect as well. Crosstalk is not yet implemented, due to lack of data.

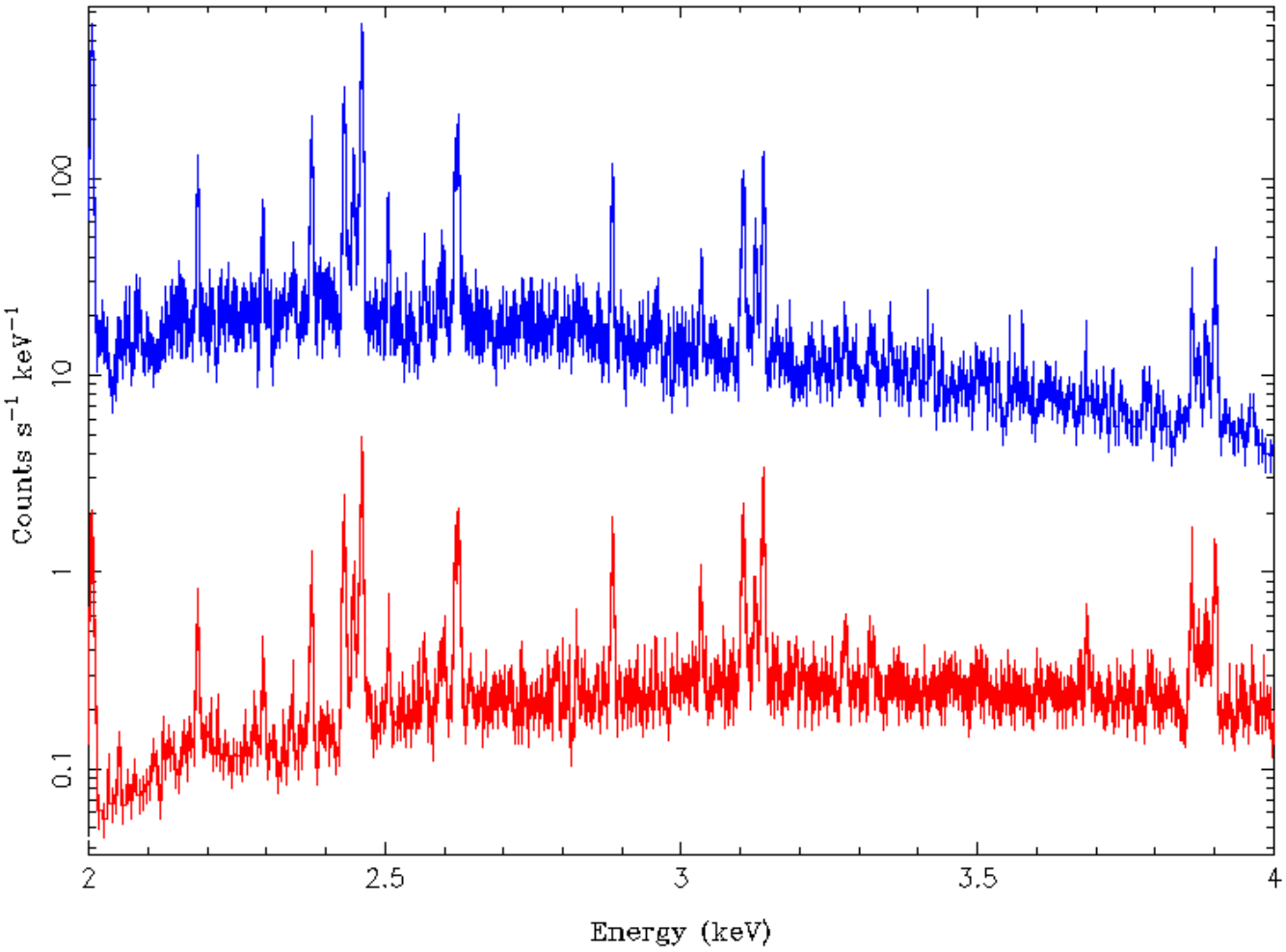
Example: Cas A, center



50 ks Resolve with Gate Valve

1 ks X-IFU with Be Filter

Example: Cas A, center



50 ks Resolve with Gate Valve

1 ks X-IFU with Be Filter

Summary: The X-IFU with SIXTE

- 1504 TES pixels in a hexagonal array
- 4' FoV
- higher flux ($>$ 10mCrab) reduces energy resolution and throughput
- science simulations with `sixtesim`, taking the most important TES physics effects into account
- physics input to the simulation pipeline by `tessim`/`xifusim`