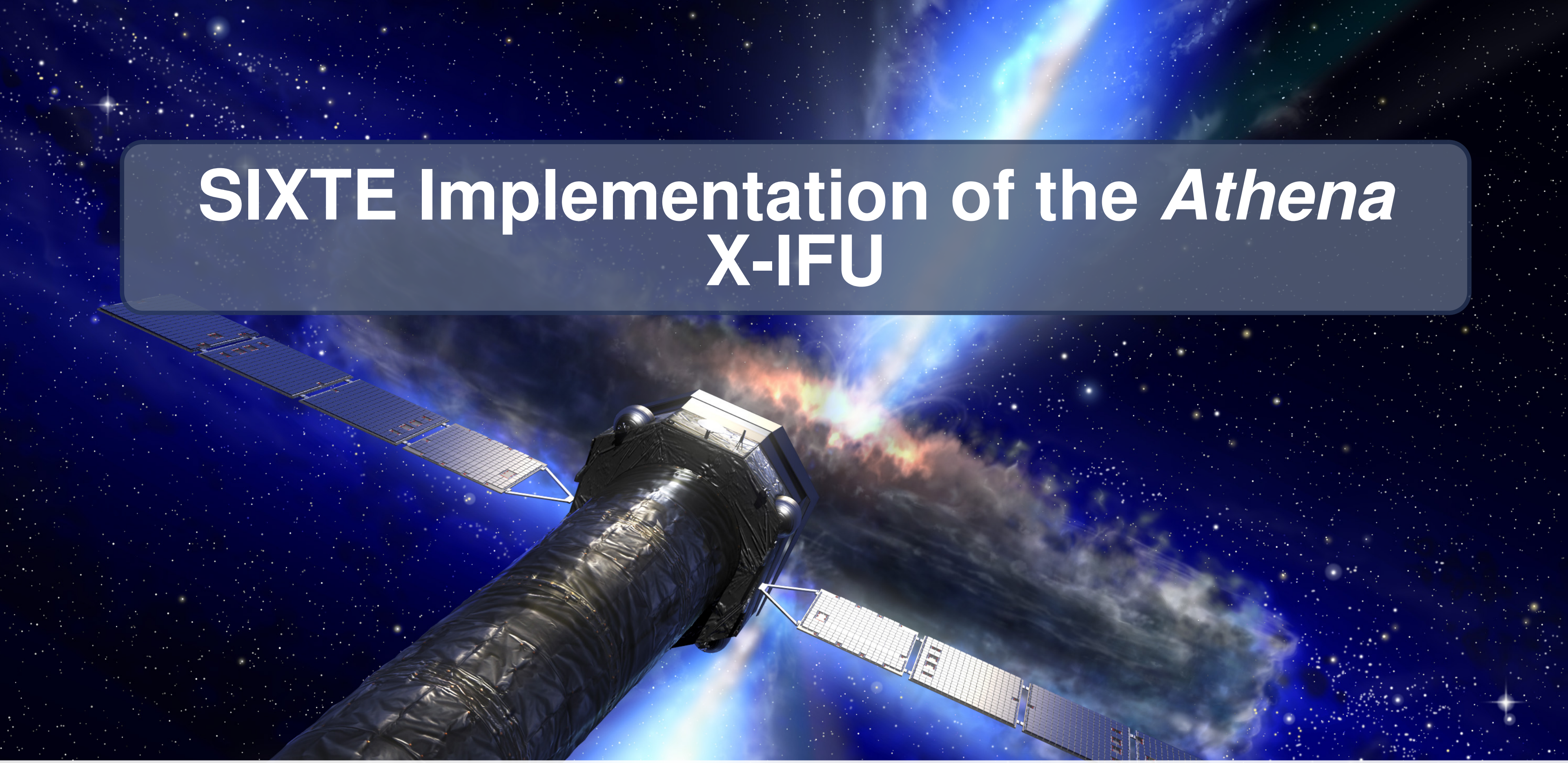
SIXTE Implementation of the *Athena* X-IFU



Christian Kirsch
Remeis Observatory & ECAP

Online Sixte Workshop — March 2022

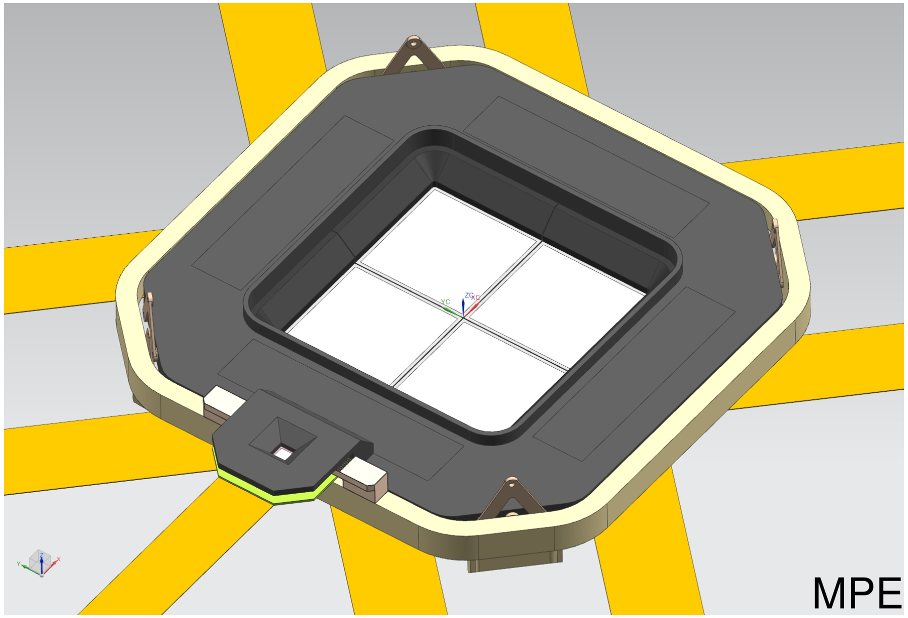
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

IFU
ATHENA X-ray Integral Field Unit

The *Athena* Instruments

WFI (Imager)

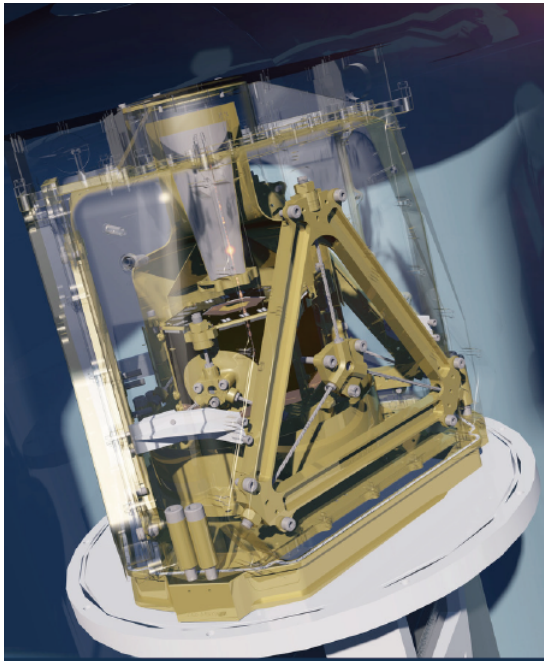
- high count-rate, moderate spectral resolution
- **large field of view**



MPE

X-IFU (Calorimeter)

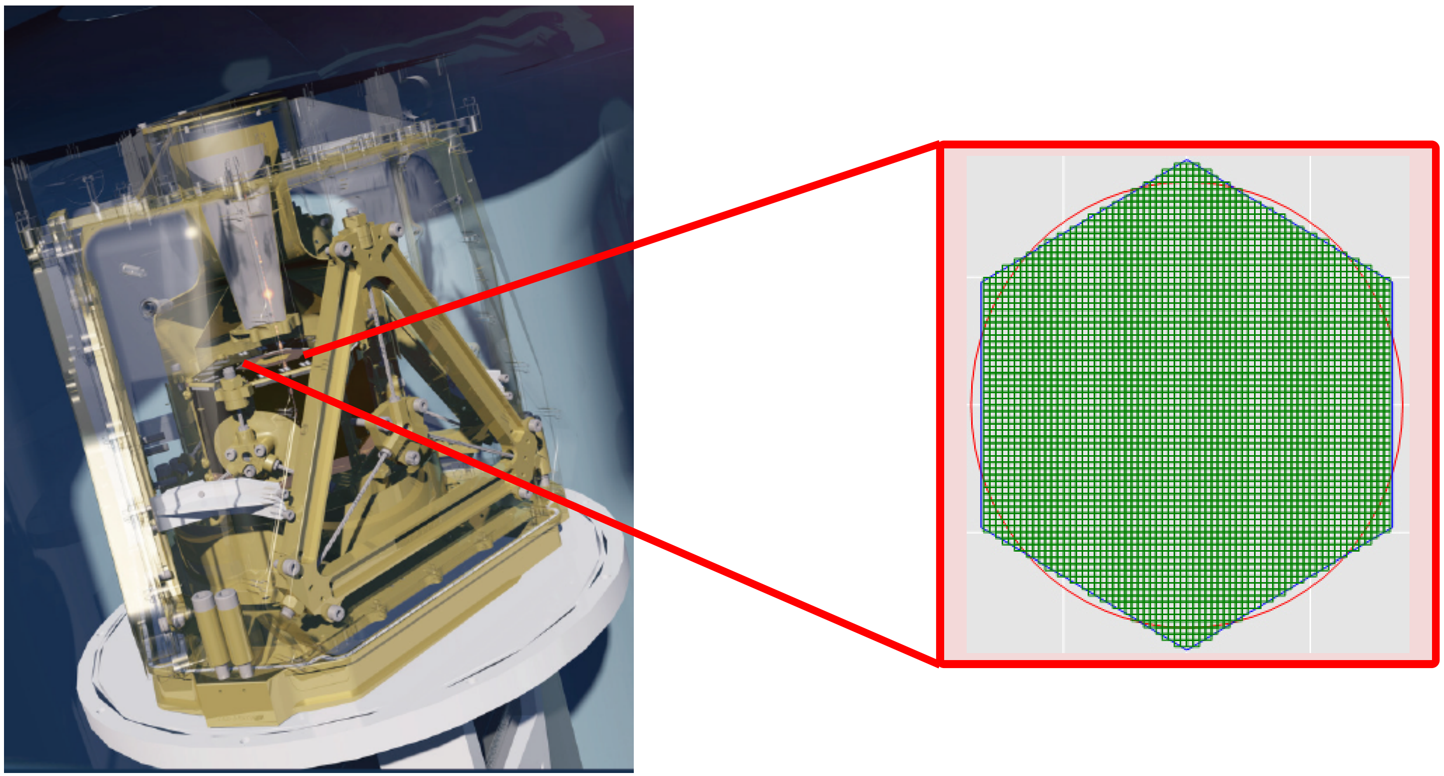
- for **high-spectral resolution imaging**
- calorimeter operating at 50 mK



X-IFU Consortium

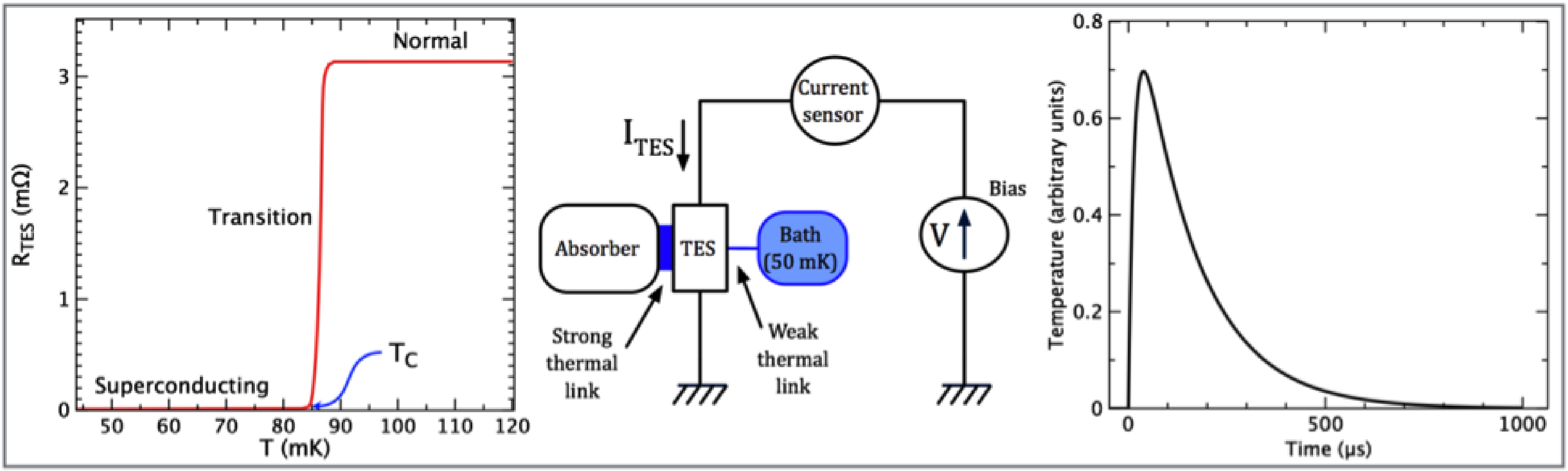
The X-ray Integral Field Unit (X-IFU)

- very high spectral resolution imaging (2.5 eV FWHM and a 5’ FoV)
- 3168 (final number being consolidated) TES (Transition Edge Sensor) pixels



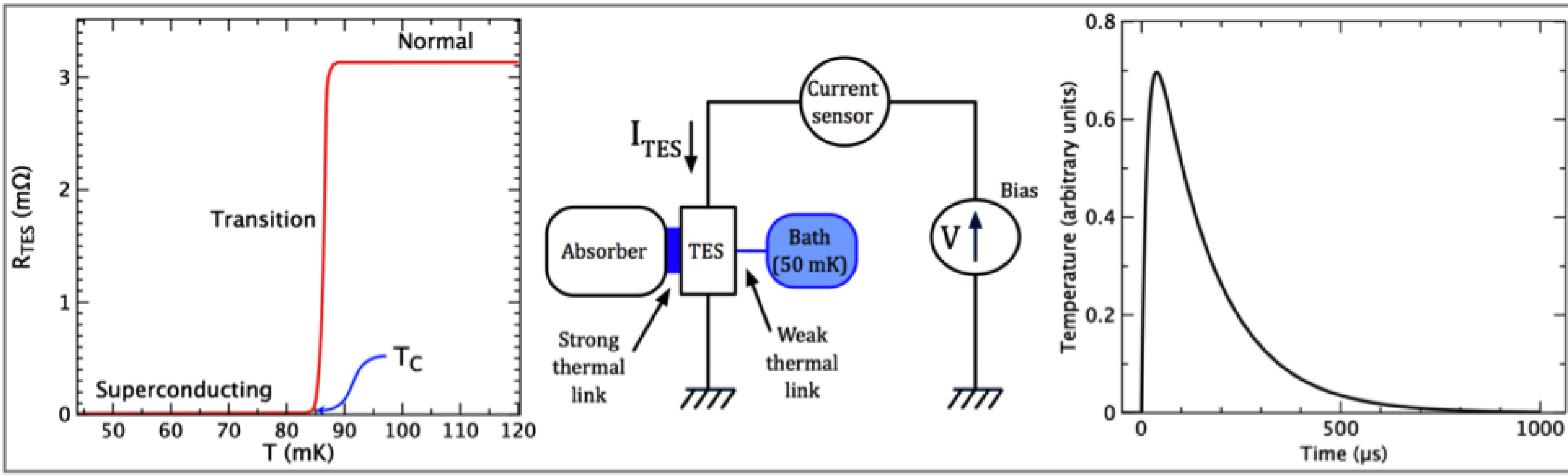
The X-ray Integral Field Unit (X-IFU)

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



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



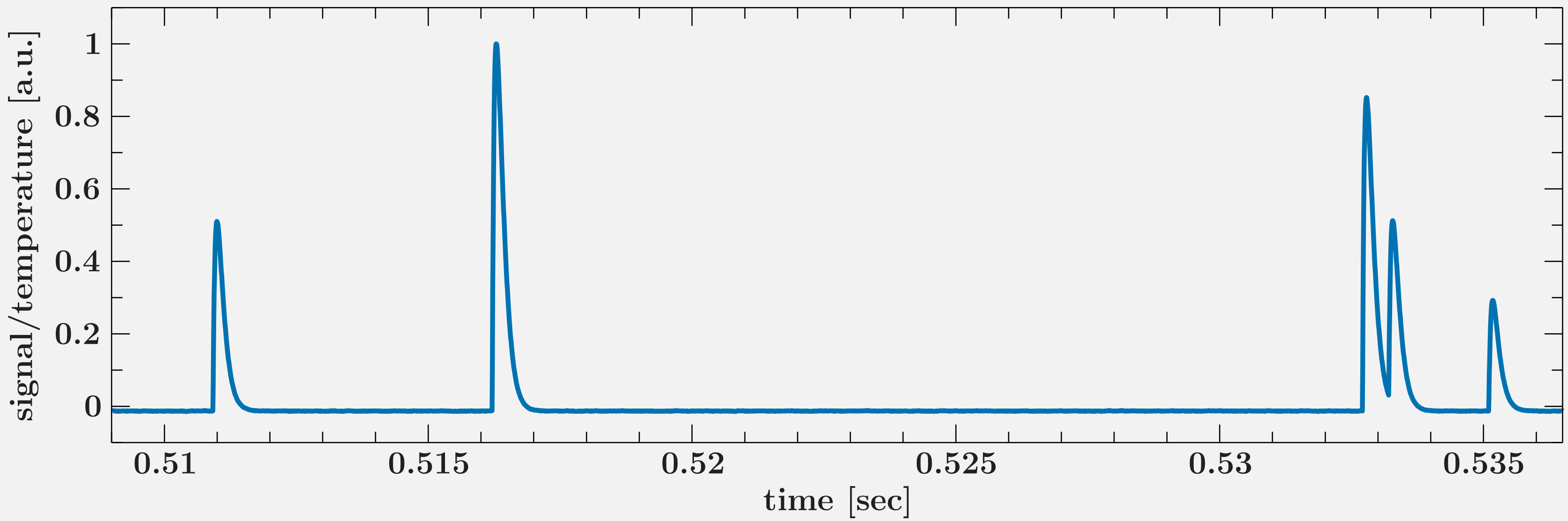
- numerical solution of differential equations for $T(t)$, $I(t)$ (Irwin & Hilton, 2005),

$$C\frac{dT}{dt} = -P_\mathrm{b} + P_\mathrm{J} + P + \mathrm{Noise} \quad \text{and} \quad L\frac{dI}{dt} = V - IR_\mathrm{L} - IR(T,I) + \mathrm{Noise}$$

- linear resistance, $R(T,I;\alpha,\beta)$; noise: Johnson of circuit, bath, excess noise
- input parameters: C, G_b, n, α, β, m, R_0, T_0, T_b, L_crit

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

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



pulses with smaller separation yield lower energy resolution
⇒ **Event Grading** depending on the source flux

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

`xifupipeline`:

- full detector array
- full imaging implemented
- fast detection simulation using response matrices (works similar to CCD-type simulations)

$\Rightarrow$ **science simulations**

`tessim/xifusim` + `SIRENA`

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

$\Rightarrow$ **Input for** `xifupipeline`

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

`xifupipeline`:

- full detector array
- full imaging implemented
- fast detection simulation using response matrices (works similar to CCD-type simulations)

⇒ **science simulations**

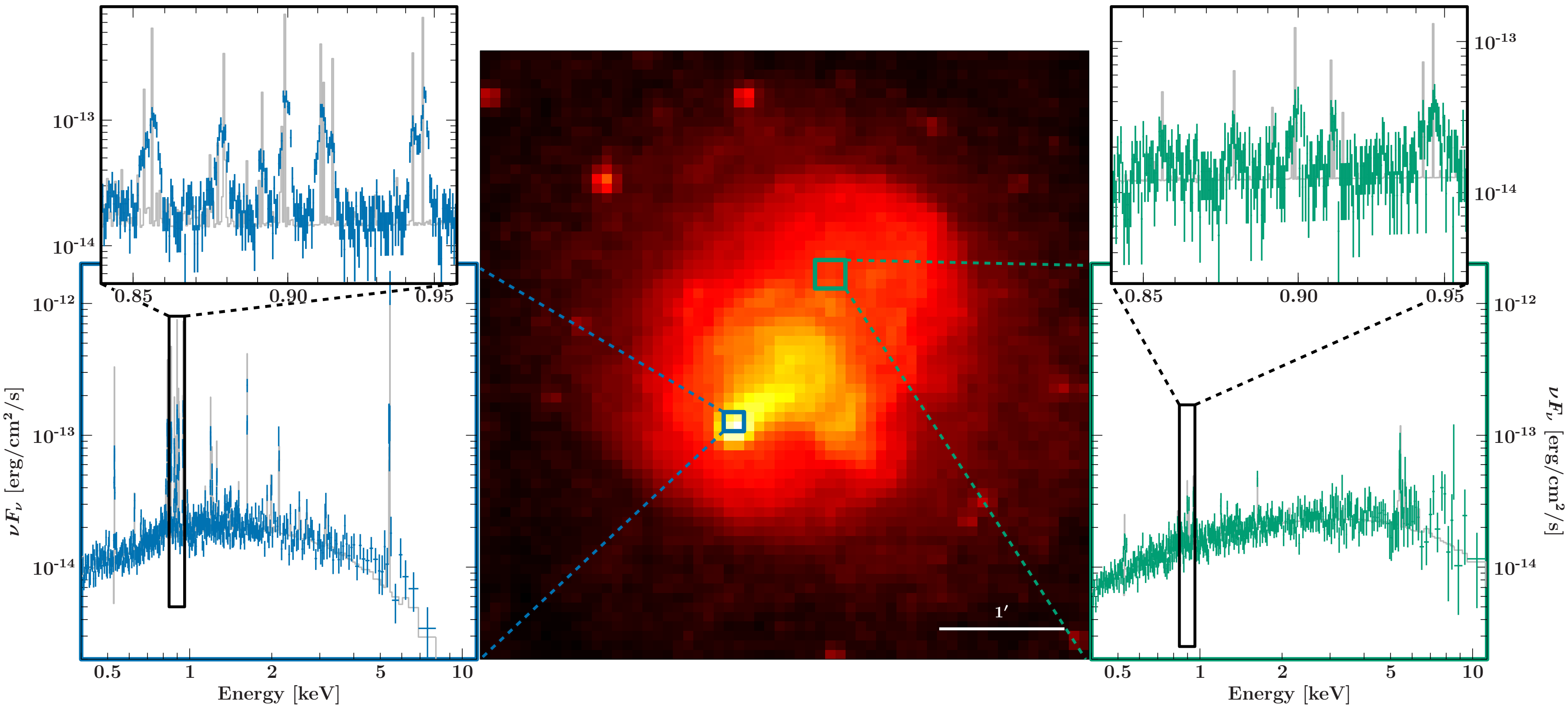
`tessim/xifusim` + `SIRENA`

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

⇒ **Input for** `xifupipeline`

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

Example: SIXTE X-IFU simulation of a Galaxy Cluster

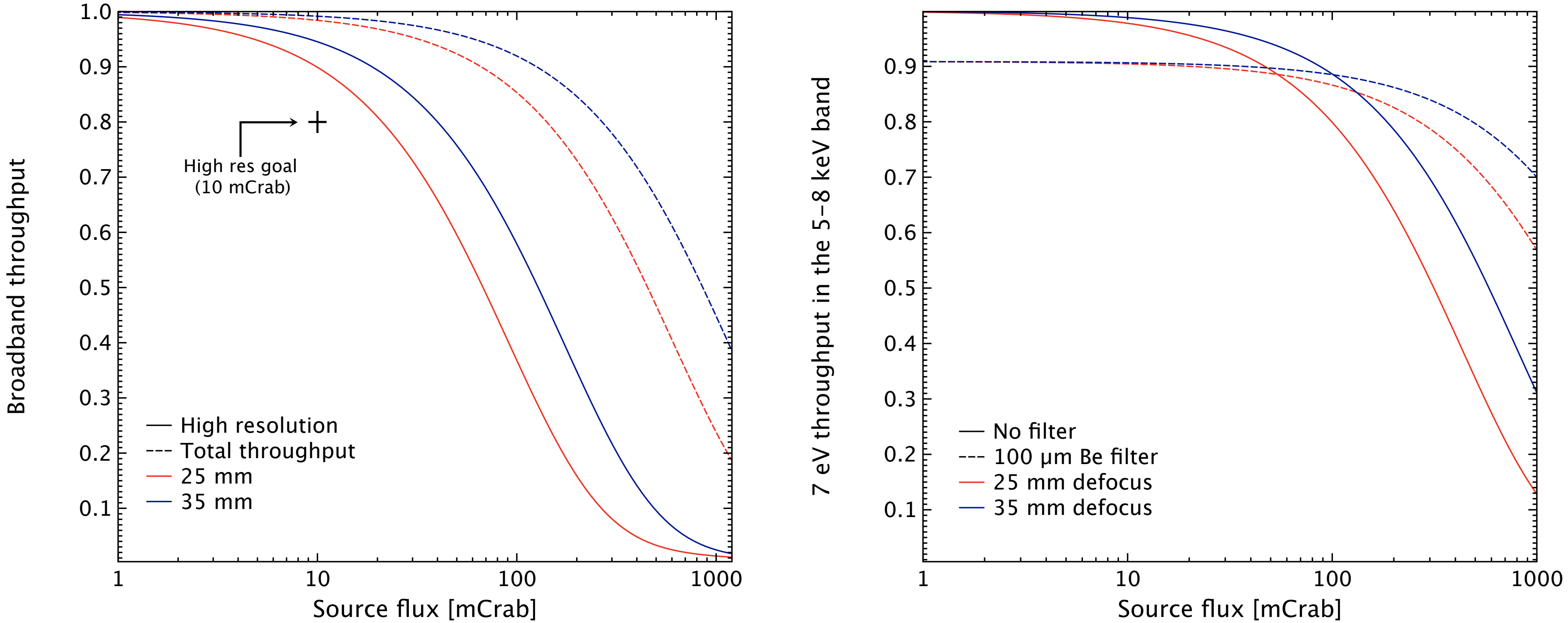


SIXTE describing, simulating, and analyzing complicated sources

X-IFU spatially resolved high-resolution spectroscopy

Performance at High Countrates (grading effect only)

defocusing of the Athena optics allows observations up to 1 Crab



Grade	Δt since previous pulse	Δt until next pulse	Energy res.
(1) High res.	$\geqslant 11.1\,\mathrm{ms}$	$\geqslant 41.3\,\mathrm{ms}$	2.5 eV
(2) Medium res.	$\geqslant 11.1\,\mathrm{ms}$	$\geqslant 2.2\,\mathrm{ms}$	3 eV
(3) Limited res.	$\geqslant 11.1\,\mathrm{ms}$	$\geqslant 0.85\,\mathrm{ms}$	7 eV
(4) Low res.	$\geqslant 11.1\,\mathrm{ms}$	–	$\sim 30\,\mathrm{eV}$

Crosstalk in SIXTE

unintended transmission of information between signal channels

Different types of crosstalk:

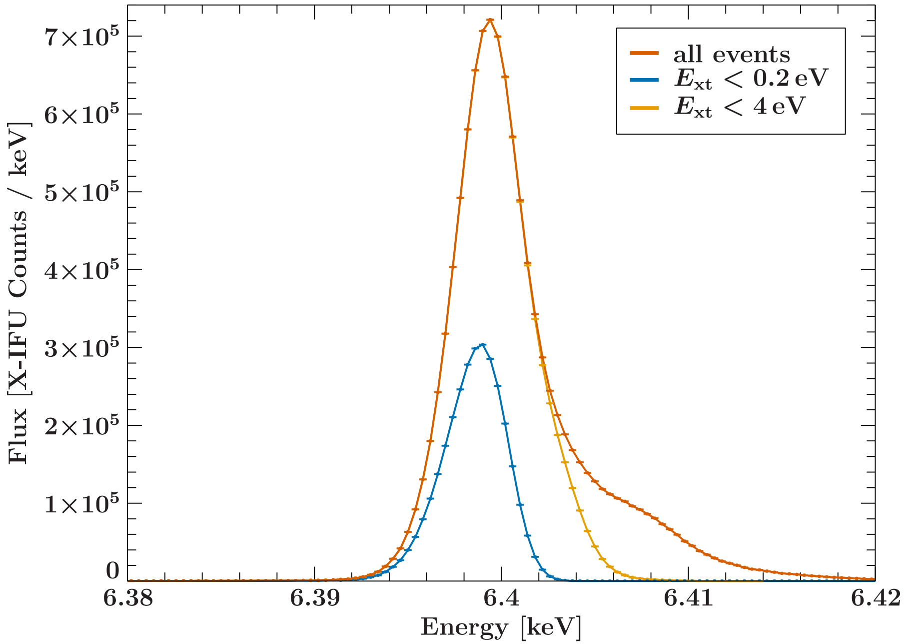
- thermal coupling of two pixels (physical neighbors)
- electrical coupling due to e.g. mutual inductance
- coupling due to multiplexed readout (TDM)

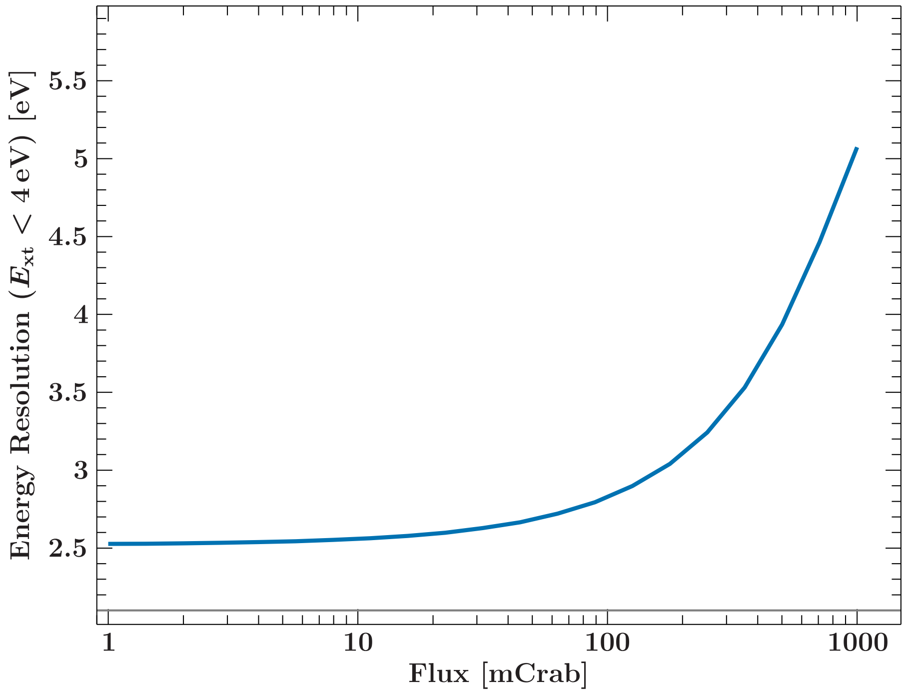
$\rightarrow$ implemented in SIXTE

crosstalk effect on events is predictable

How does Crosstalk affect X-IFU Events?

simulation of a narrow emission line (1 Crab)





⇒ remove events which are *strongly* effected by crosstalk

trade-off between energy resolution and throughput ⇒ 10 eV resolution with 50% throughput @ 1 Crab

XML files

`xifupipeline` requires two XML files to run:

Standard SIXTE XML (`XMLFile`)

- Same format as e.g. WFI XML files
- Defines ARF, PSF, background
- Four configurations: In-Focus and Defocussed, With and Without Be-Filter

X-IFU specific XML (`AdvXml`)

- Defines data for Grading (including RMF) and Crosstalk
- Specifies readout channels, pixel positions

In practice: `AdvXml` is fixed, `XMLFile` chosen depending on observation (mostly source brightness)

Summary: The X-IFU with Sixte

- 3168 (final number TBC $\rightarrow$ Red Book) TES pixels in a hexagonal array
- 5’ FoV
- higher flux ($>$ 10mCrab) reduces energy resolution and throughput
- science simulations with `xifupipeline`, taking the most important TES physics effects into account
- physics input to the simulation pipeline by `tessim`/`xifusim`

Tutorial: Extended Source Simulations (continued)

We begin by comparing observations from the X-IFU and WFI in the case of Cas A

- simulate a 100 s observation of Cas A (using the simput generated yesterday) for the X-IFU using `xifupipeline`.
- construct an image from the event file using `imgev`. How does it compare to the WFI?
- create spectra for both observations via `makespec`. For this, use the same extraction region in RA and Dec in both (keyword: `EventFilter`) and compare them.

A xifupipeline command is shown in the Simulator Manual, Sect. 10.7

Tutorial: Simulating Galaxy Clusters

The main difficulty of simulating a galaxy cluster observation lies in the building of a suitable SIMPUT file containing all the information probed by a high-resolution integrated field unit like the X-IFU.

- download the `X-IFU_clusters_tutorial.tgz` file containing all data to simulate A2146 (already uploaded on SciServer)
- construct a point source XSPEC model file with an absorbed `apec` model
- create a SIMPUT file of A2146 with `simputmultispec`, using the given temperature and abundance map such that the source spectrum changes over the source
- look at the simput with `fstruct` and/or `fv` and try to understand what `simputmultispec` does
- simulate the source with `xifupipeline`
- extract spectra from different source regions and compare them

detailed commands in the Simulator Manual, Sect. 10.7

Tutorial: High Count-Rate Observations (Optional)

We will now examine the effect of high count-rates on the energy resolution of the X-IFU, and how it can be mitigated

- Prepare the model: Build a 1 mCrab model file (c.f. simulator manual section 10.2.2), adding a sharp gaussian emission line at 6.4 keV (XSPEC model `gauss, sigma=0.001 keV, norm=0.1`)
- Build a simput file using this model, setting its flux to the equivalent of 1 Crab (`srcFlux=2.137e-8`)
- Run a 10 s simulation using `xifupipeline`, with the `doCrosstalk` option set to `all`, and extract the spectrum using `makespec`. Plot the emission line! Does it look like a Gaussian?
- Run the same simulation, now using the defocused option (change `XMLFile` to `.../xifu_baseline_35mm.xml`). Extract the spectrum again, and compare the shape of the emission line with the previous simulation.
- Compare the counts distribution on the detector between simulations.