Simulating *Athena* with Sixte: The WFI and X-IFU instrument

Christian Kirsch & Maximilian Lorenz, Remeis Observatory & ECAP

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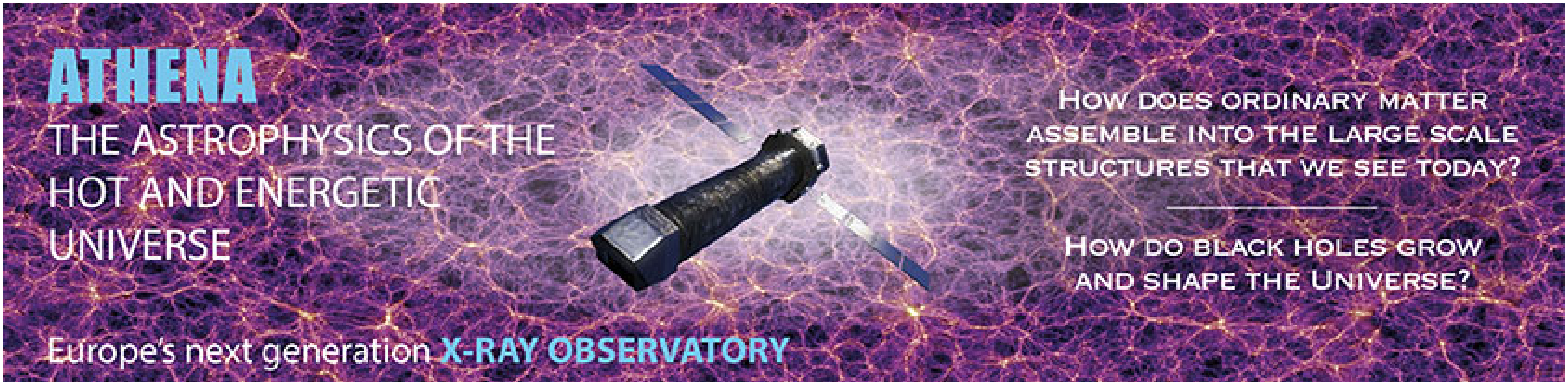
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

WFI ATHENA

IFU ATHENA X-ray Integral Field Unit

The *Athena* Mission

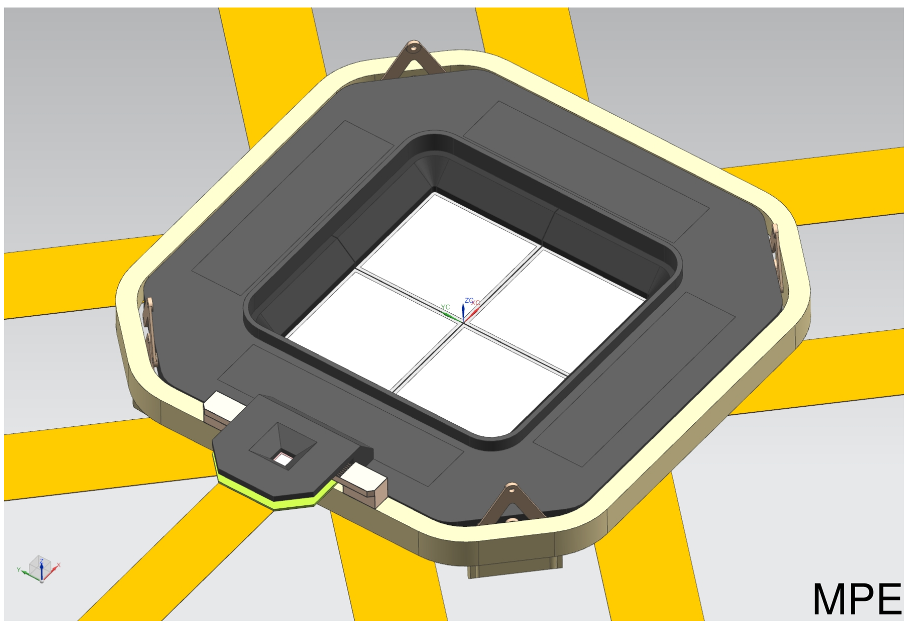


- to be **launched to L2 in $\sim$2030** as the second ESA L-class mission
- **large consortium**, members from Europe, US, and Japan ($>$ 200 members)
- two **instruments** on board:
  - Wide Field Imager (WFI)
  - X-ray Integral Field Unit (X-IFU)

The *Athena* Instruments

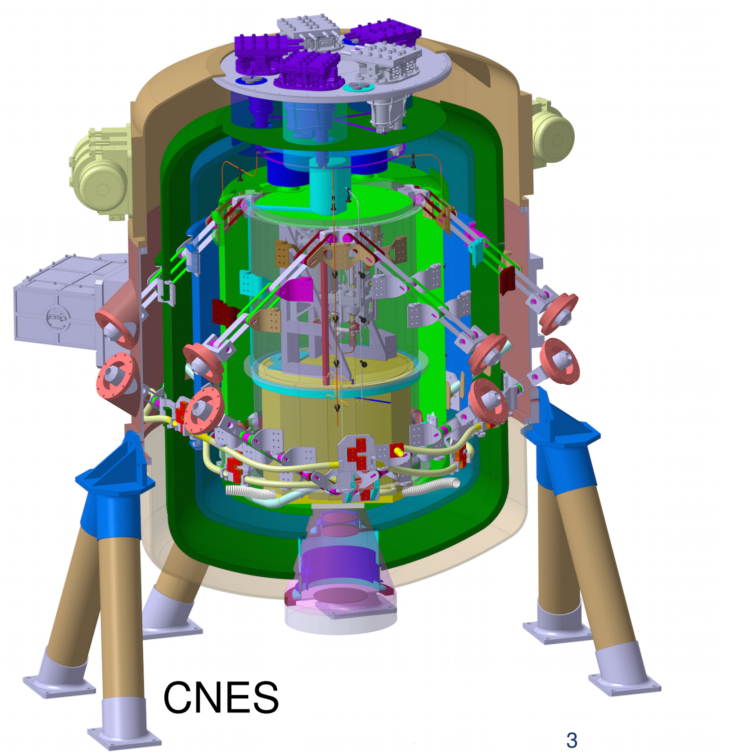
WFI (Imager)

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



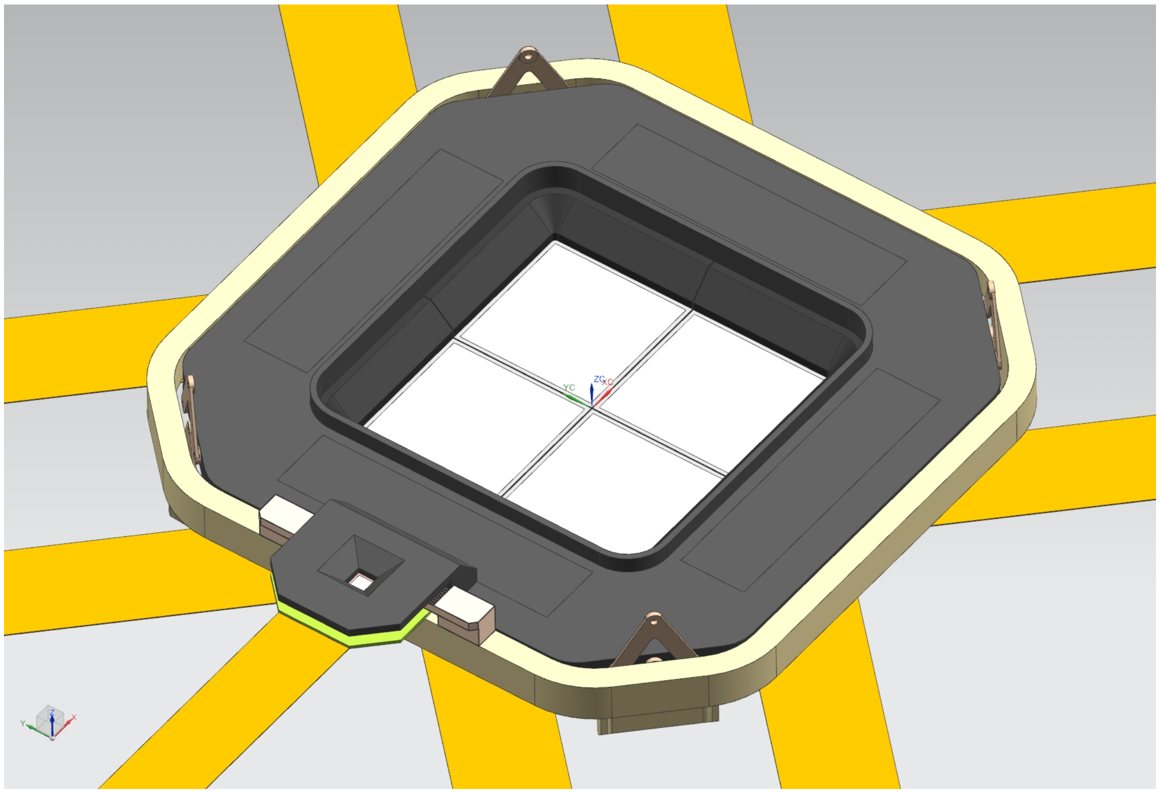
X-IFU (Calorimeter)

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



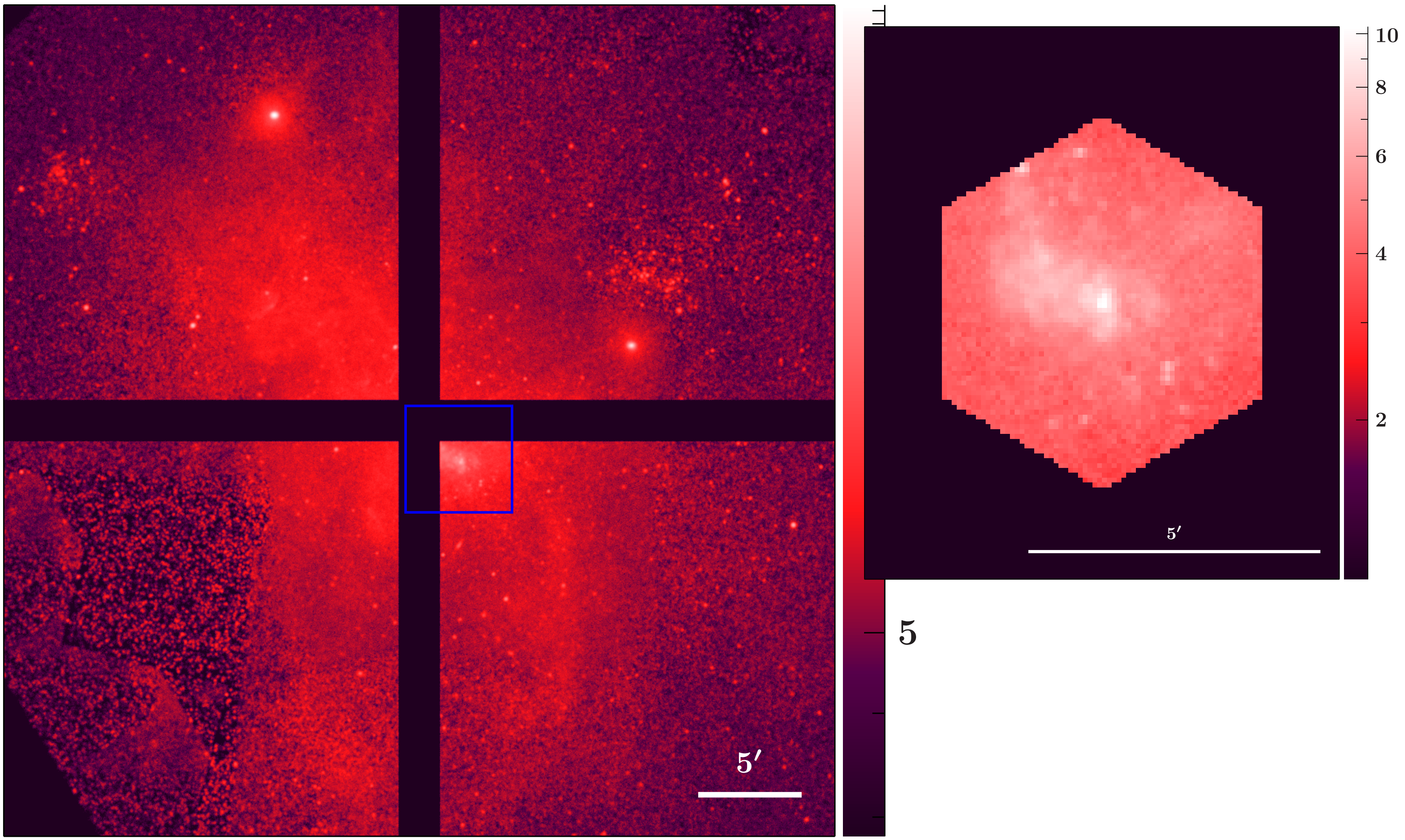
The Wide Field Imager (WFI)

Large Detector Array and Fast Detector (35 mm defocused)

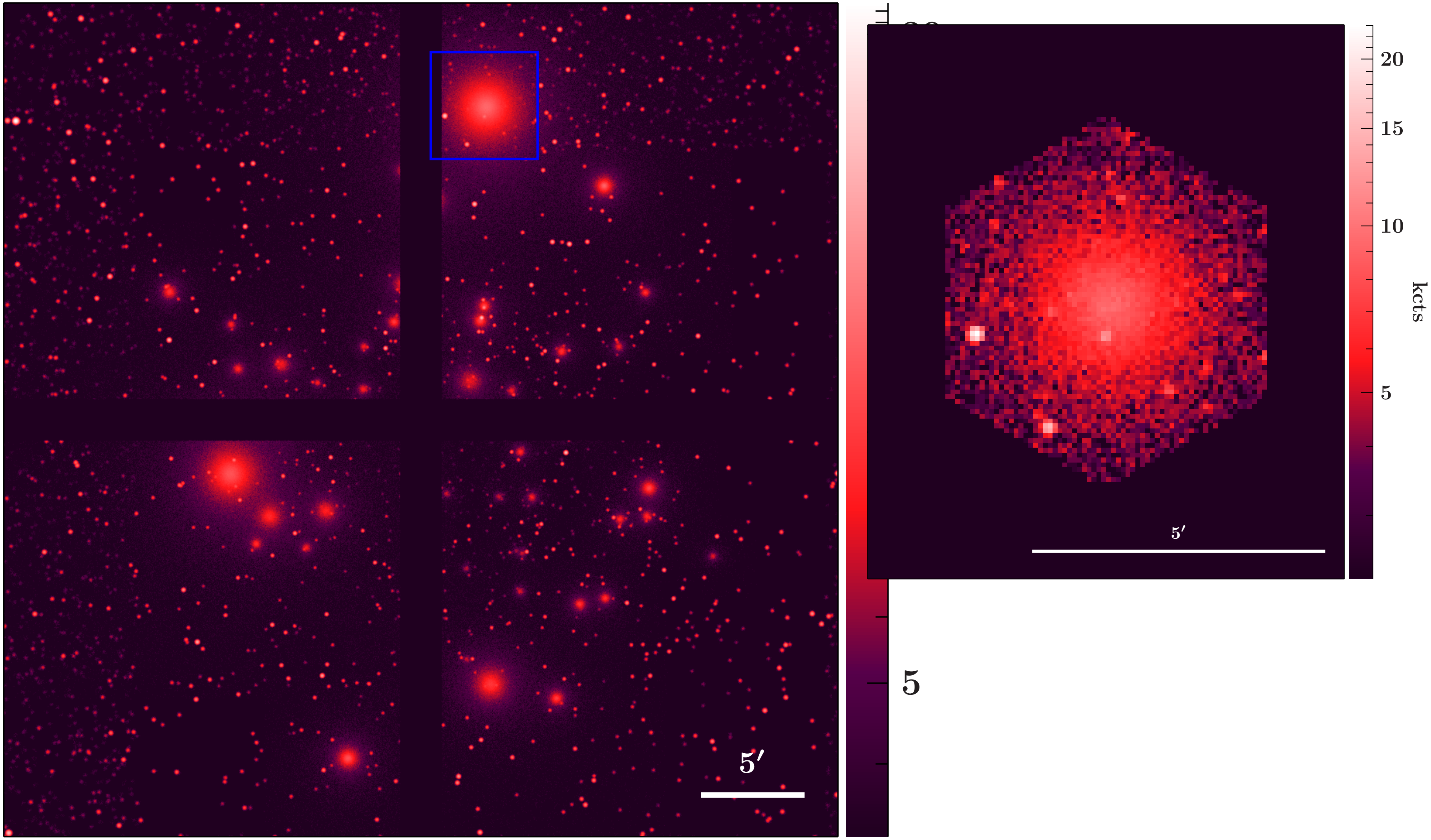


- DePFET active pixel technology (similar to CCD with line-by-line readout)
- spectral resolution: $\leq$ 170 @ 7keV
- high count-rate capabilities (10 Crab)
- large FOV: $40' \times 40'$

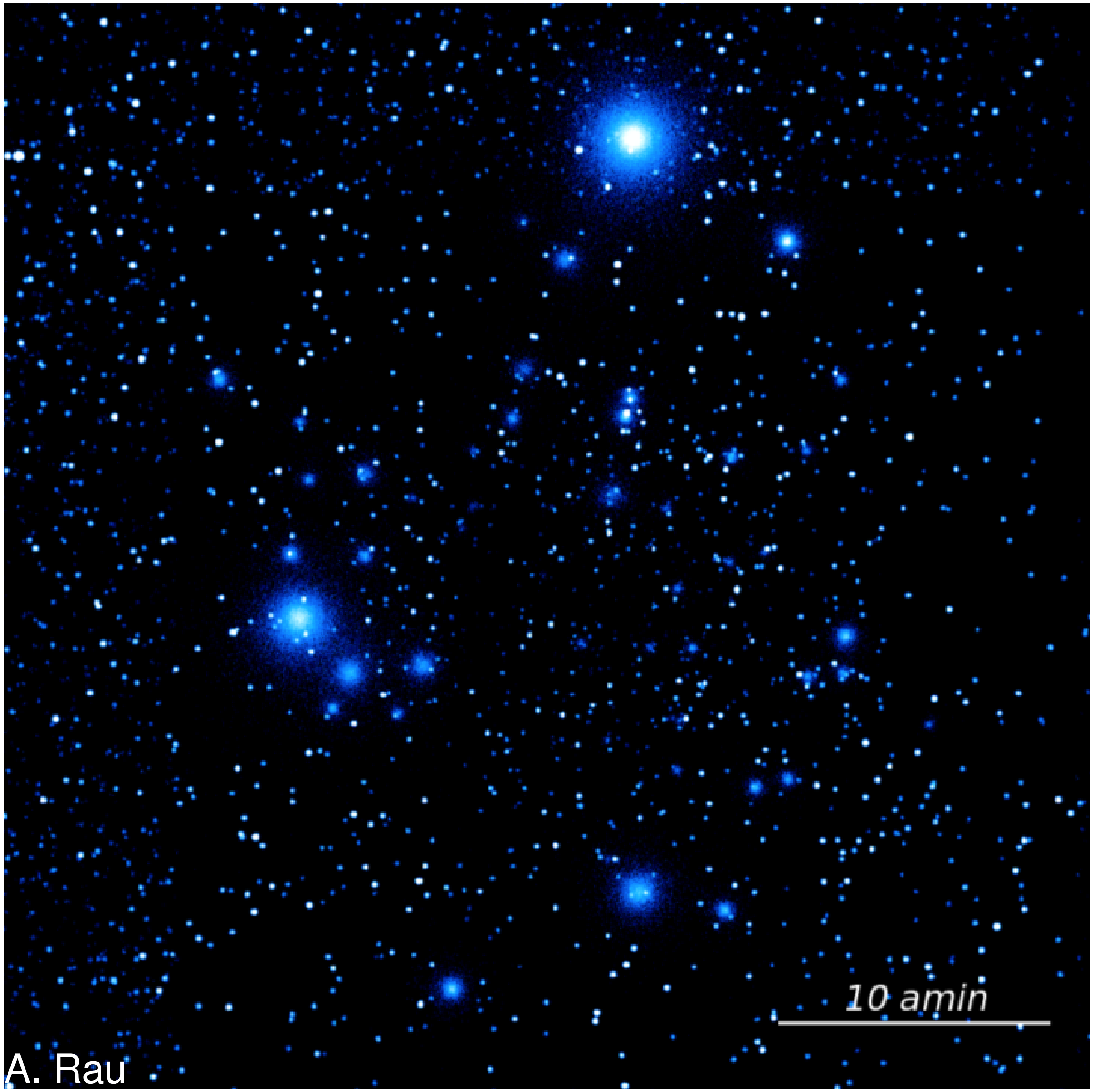
Example: The Galactic Center with *Athena*



Example: The Chandra Deep Field South with *Athena*

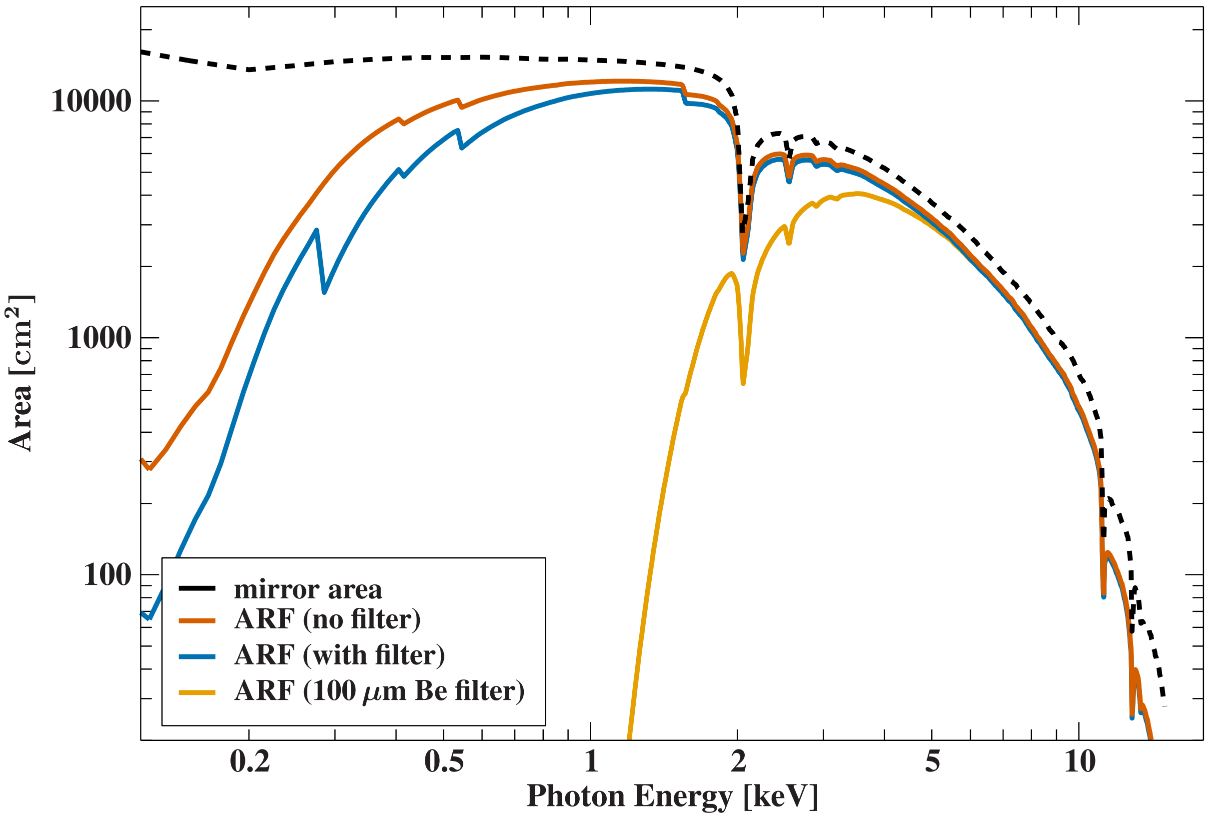


Example: The Chandra Deep Field South with *Athena*



dithering efficiently removes gaps between the chips

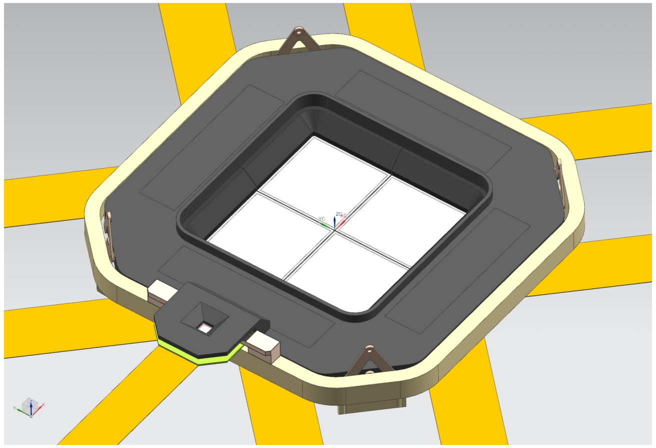
WFI Effective Area



thick Be filter $\Rightarrow$ removes photons below 2 keV

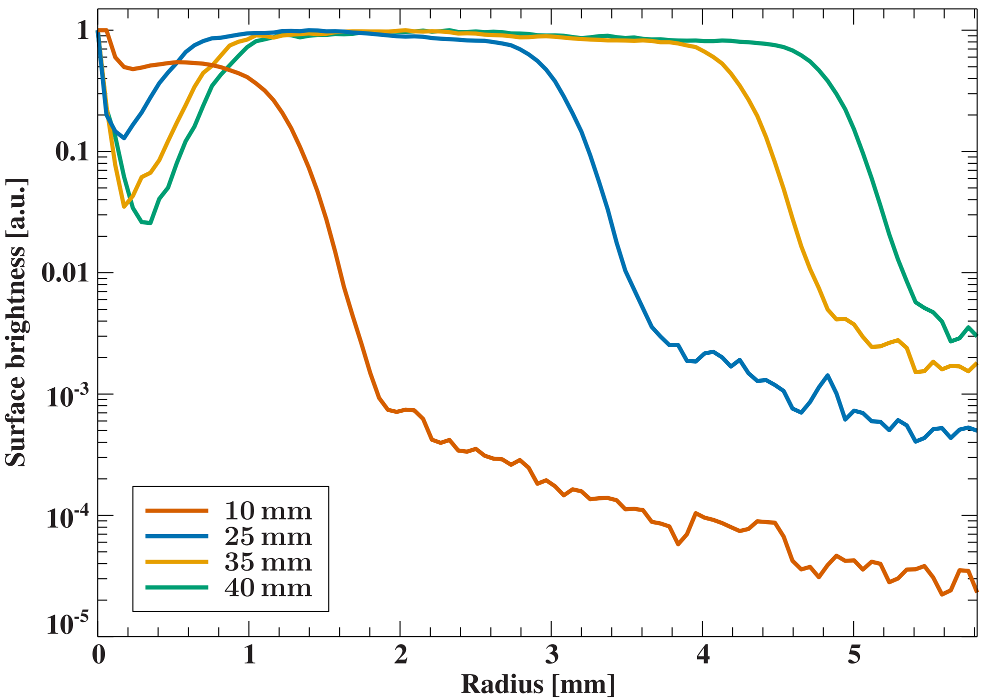
Different modii of the WFI (in SIXTE)

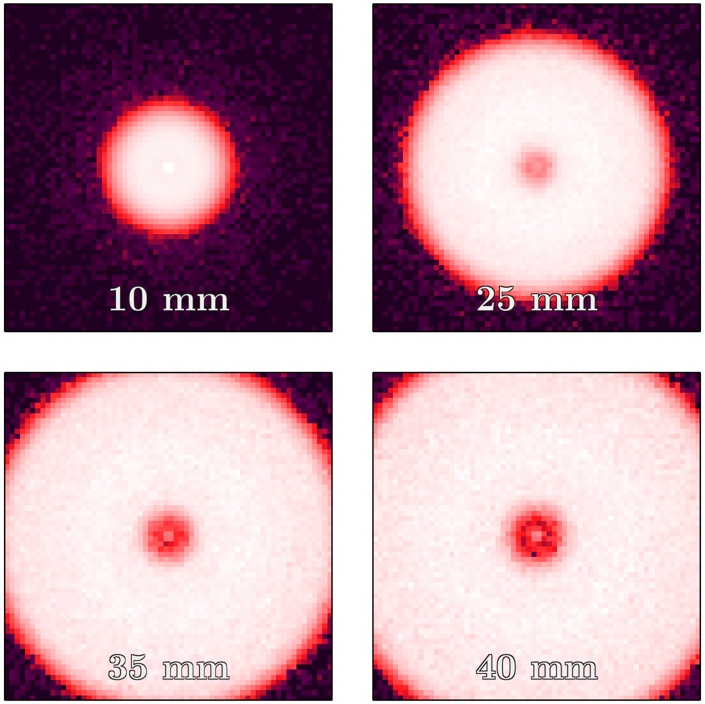
Name	Size (rows × columns)	time resolution	defocusing
large	512 × 512	5018 μs	—
w64	64 × 512	627 μs	—
w32	32 × 512	314 μs	—
w16	16 × 512	157 μs	—
w64df	64 × 512	627 μs	35 mm
fast	64 × 64	80 μs	35 mm
fastBe	64 × 64	80 μs	35 mm



- Large Detector Array and Fast Detector
- Fast Detector defocused by default
- Option for a thick Be filter

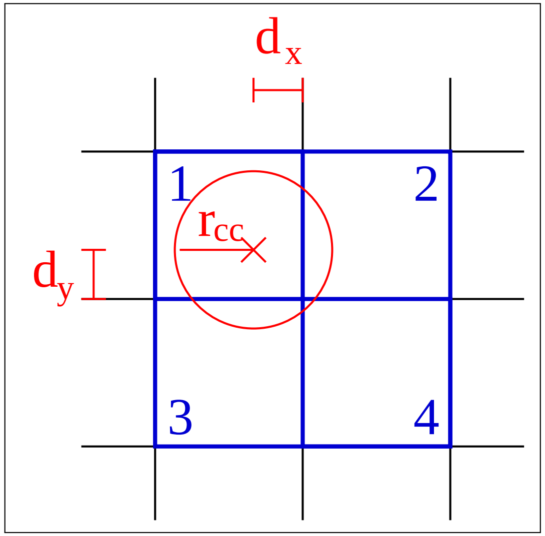
Defocusing of the Fast Chip

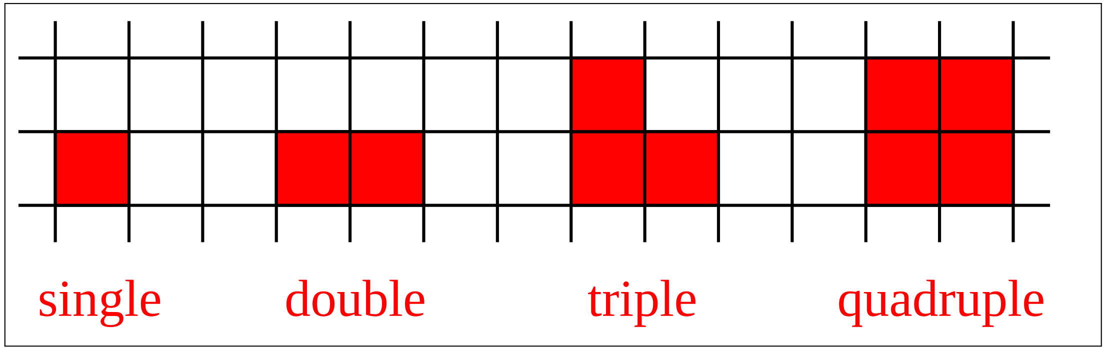




⇒ defocusing distributes photons over larger area (**35 mm is optimal**)

Event Detection in SIXTE for the WFI



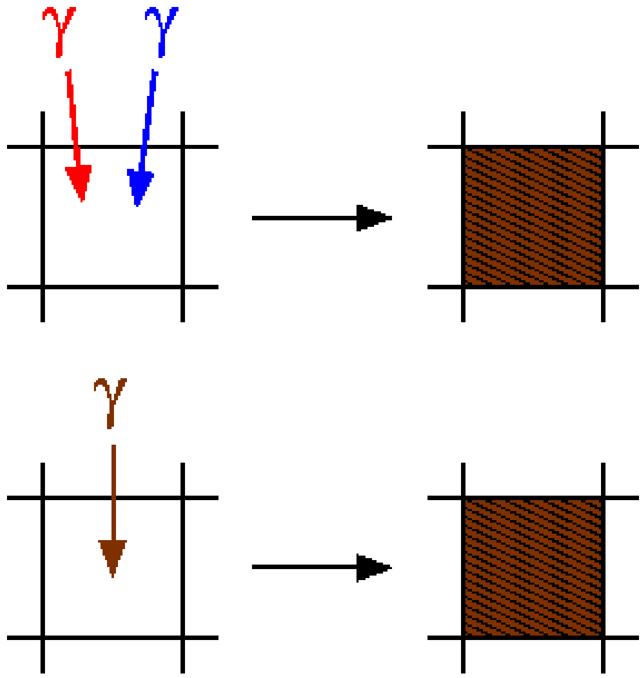


patterns are recombined for each frame in the pattern analysis

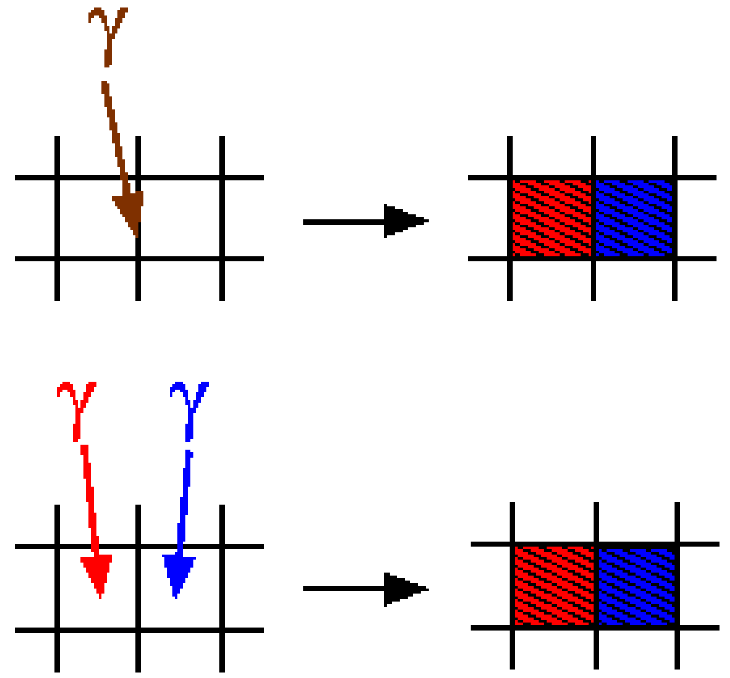
$\Rightarrow$ invalid patterns rejected

Pile-up in the WFI

energy pile-up

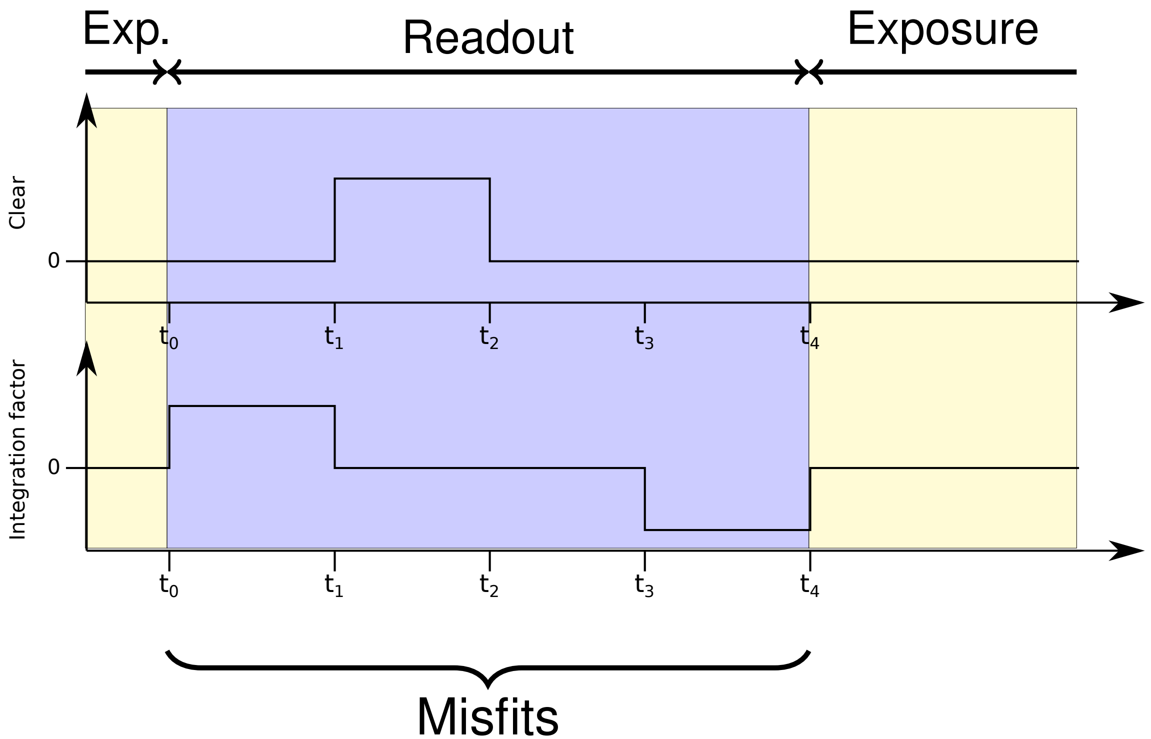


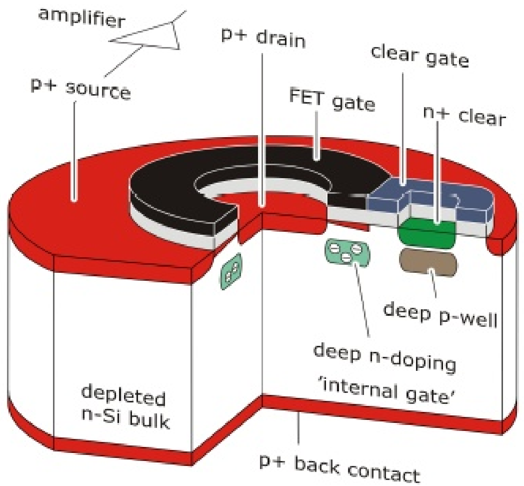
pattern pile-up



pile-up events distort spectral shape

WFI DePFET read-out implementation in SIXTE

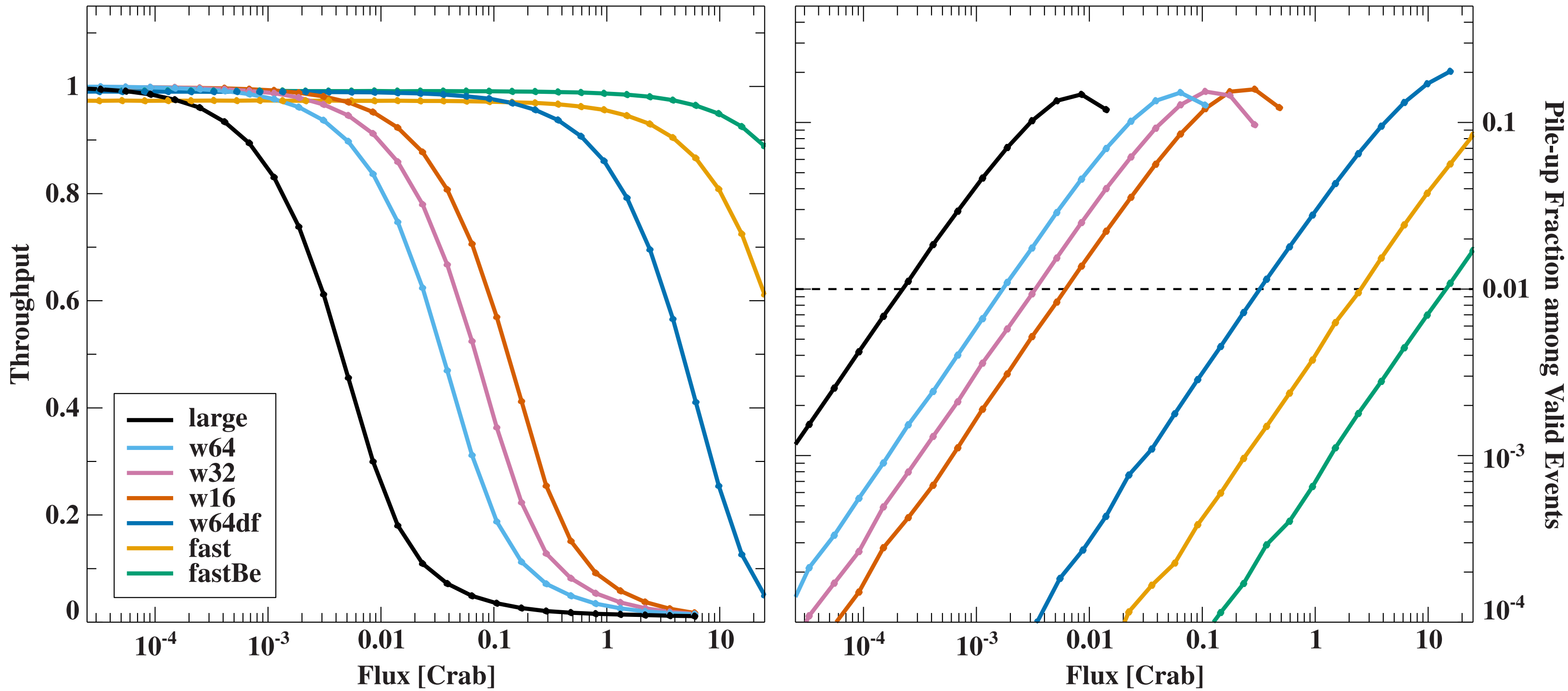




If photon hits during the read out: measured charge is affected
$\Rightarrow$ Energy E wrong ("Misfit")

this is most relevant for window modes or the fast detector

Bright Sources with the WFI



throughput: ratio of valid events to number of incident photons

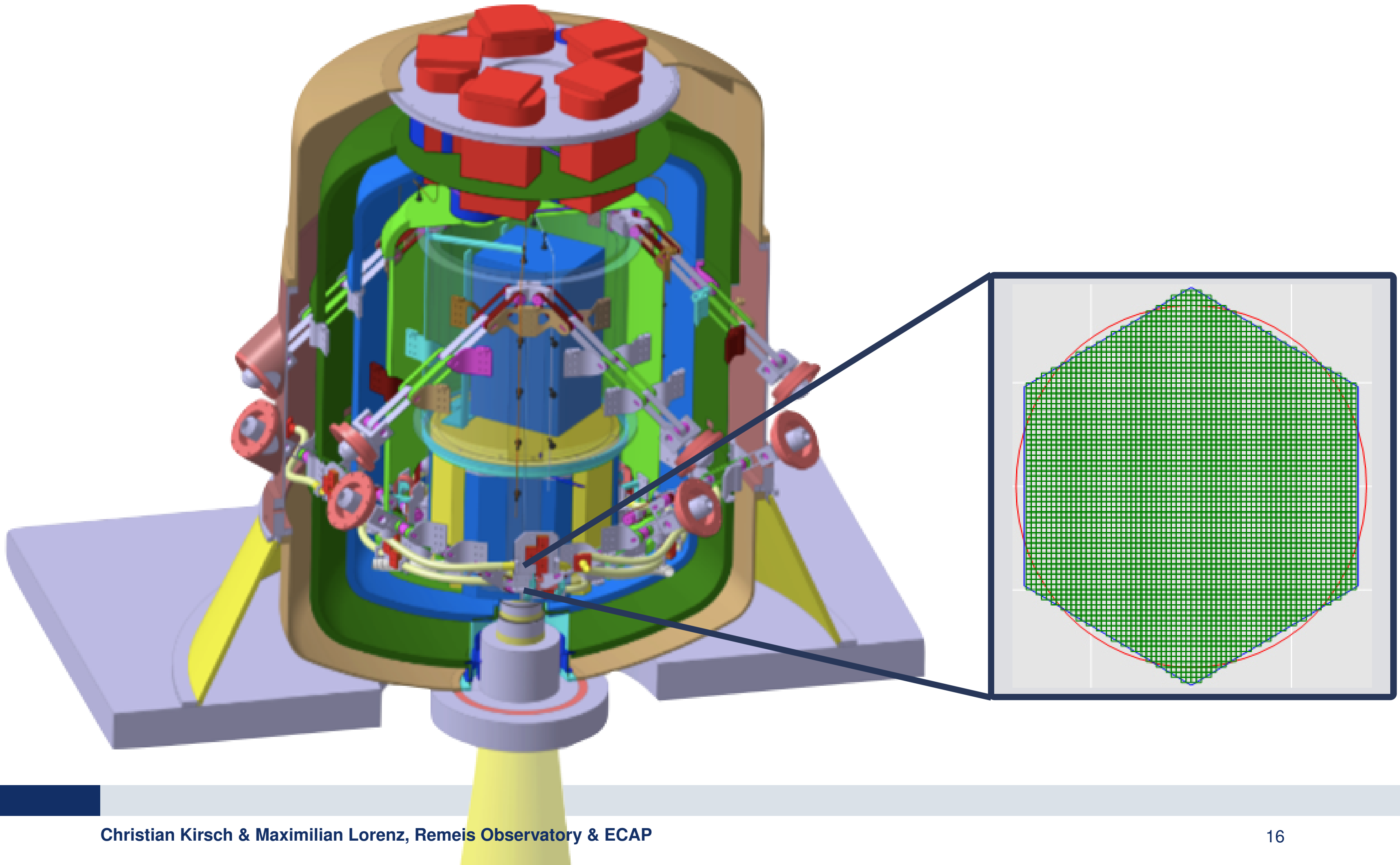
- slightly better bright source performance with smaller mirror
- fast chip allows to observe sources above 1 Crab
- up to 10 Crab with Be filter possible

Summary: The WFI with Sixte

- DePFET technology: active pixels, no line shifts $\rightarrow$ misfits if pixel is hit during readout
- observations possible up to a few Crab, plus a thick filter for even brigther sources
- large 40' FoV made of 4 chips $\rightarrow$ requires dithering
- simulations possible for the full 4 chip LDA (`athenawfisim`), or only a single chip (LD, or the 35 mm defocused FD) with `runsixt`

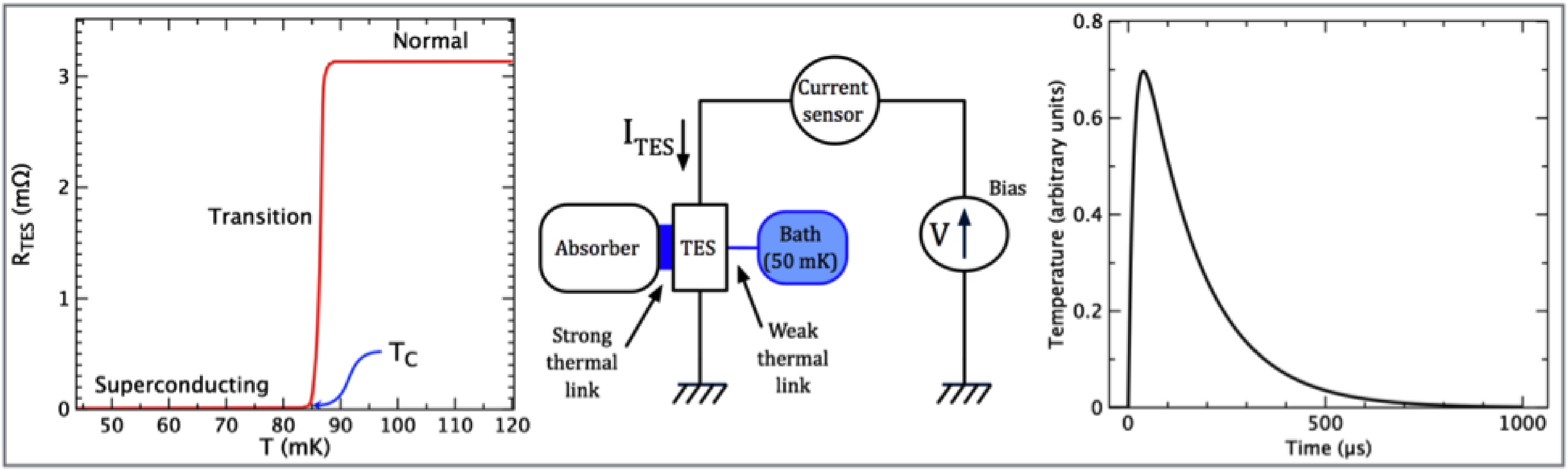
The X-ray Integral Field Unit (X-IFU)

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



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



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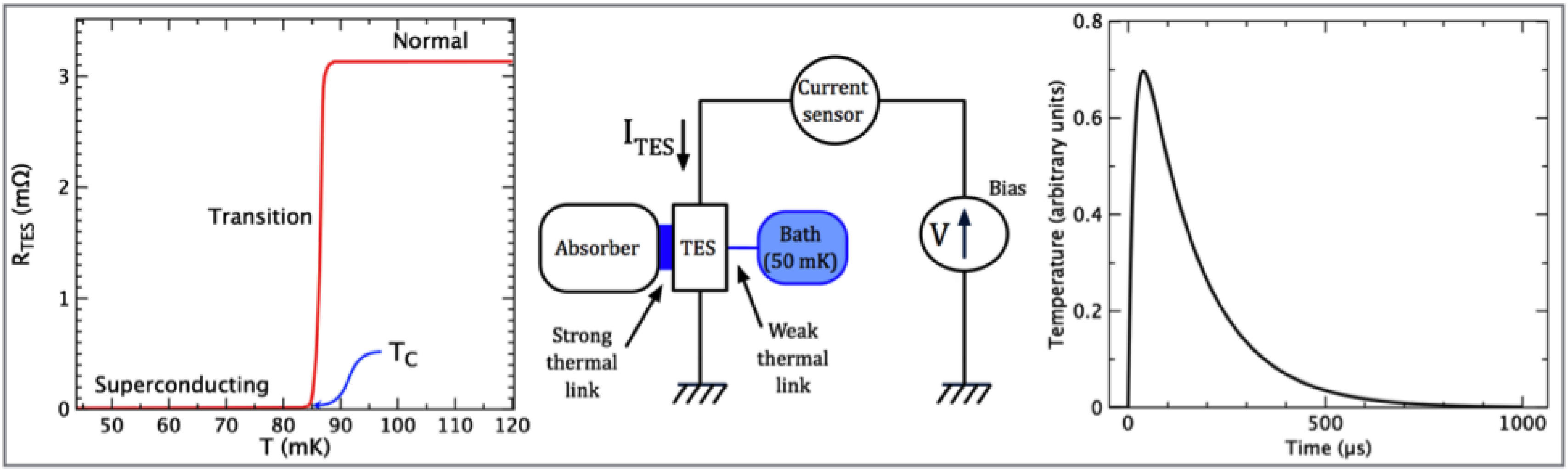

- numerical solution of differential equations for $T(t)$, $I(t)$ (Irwin & Hilton, 2005),

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

- 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

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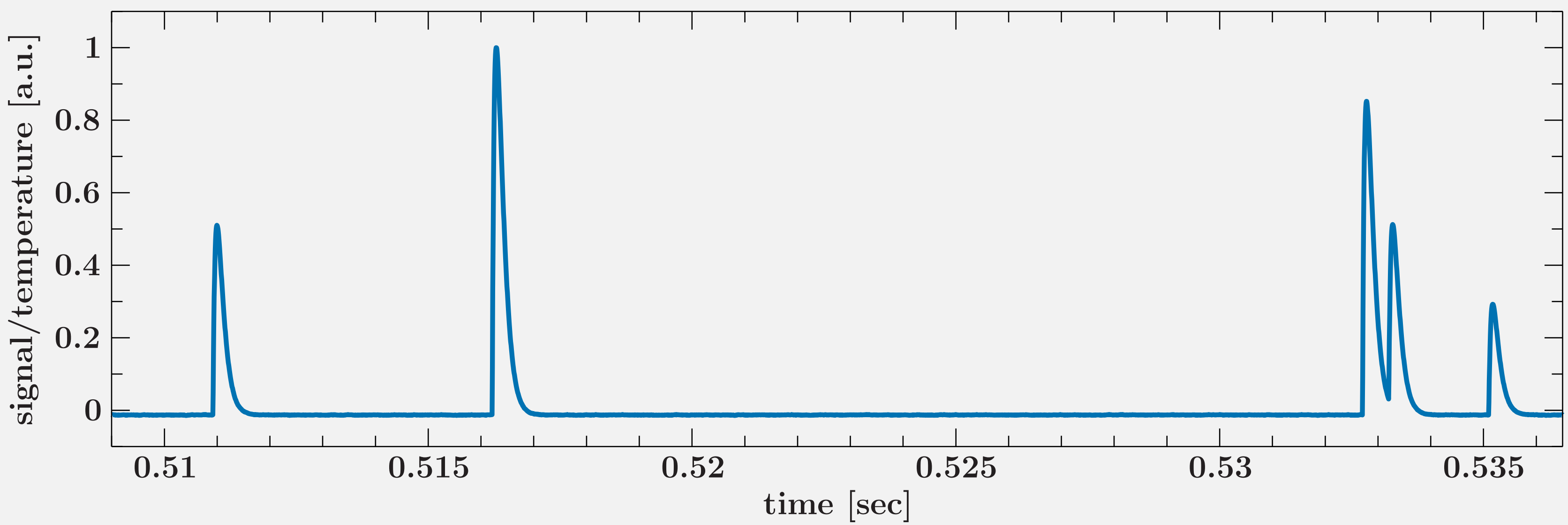

pulses with smaller separation yield lower energy resolution
⇒ **Event Grading** depending on the source flux

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)

⇒ **science simulations**

`tessim/sirena`

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

⇒ **Input for `xifupipeline`**

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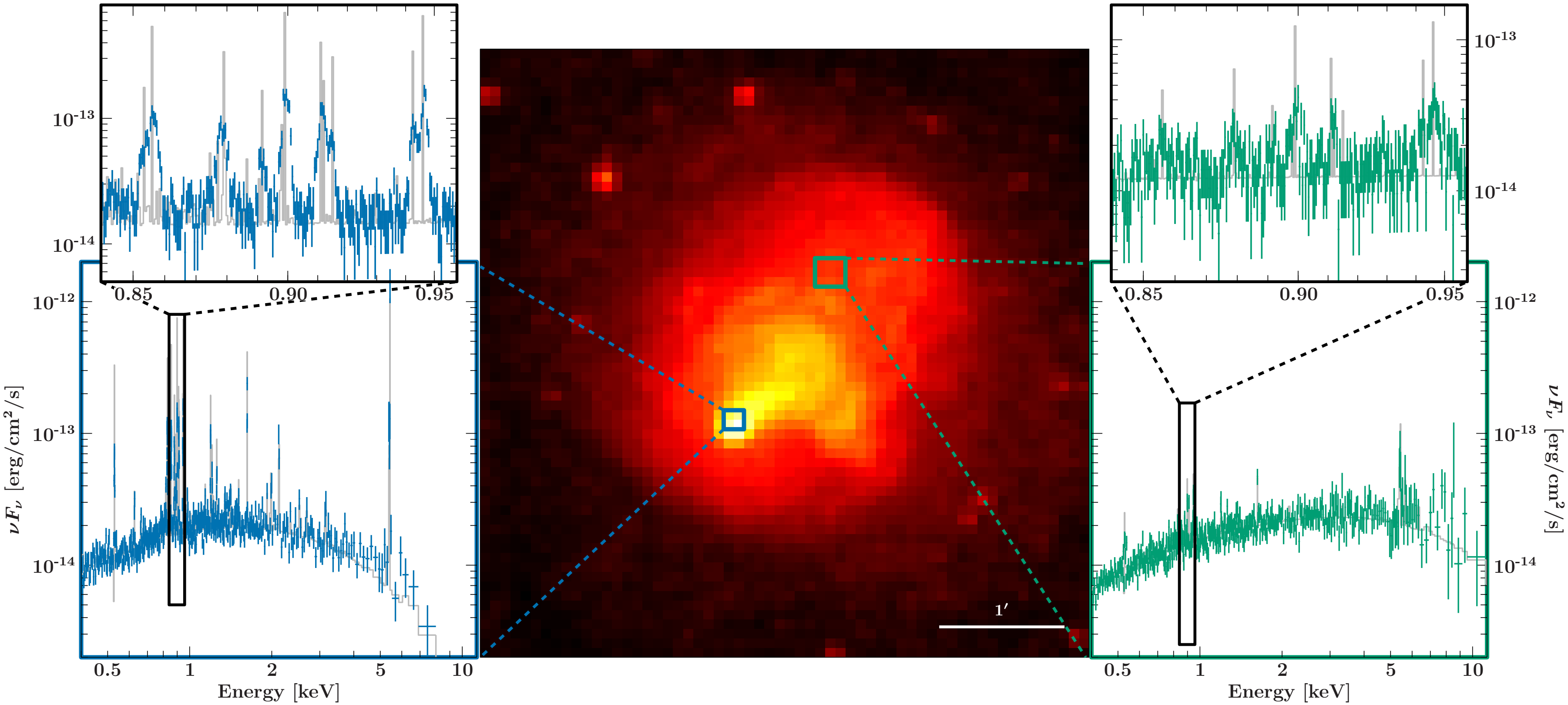
⇒ **Input for** `xifupipeline`

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

Example: SIXTE X-IFU simulation of a Galaxy Cluster

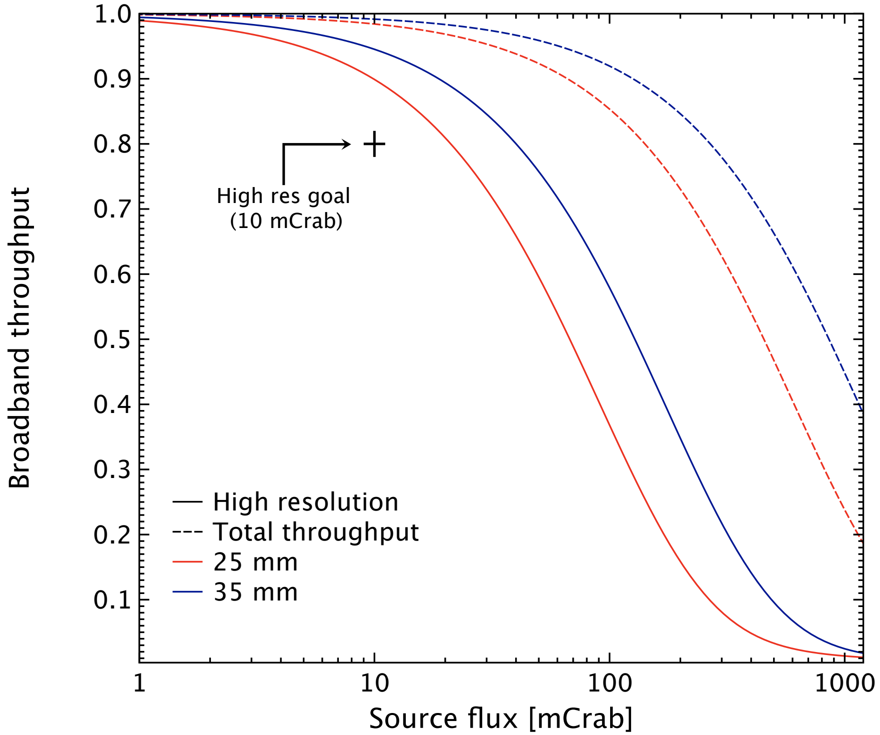


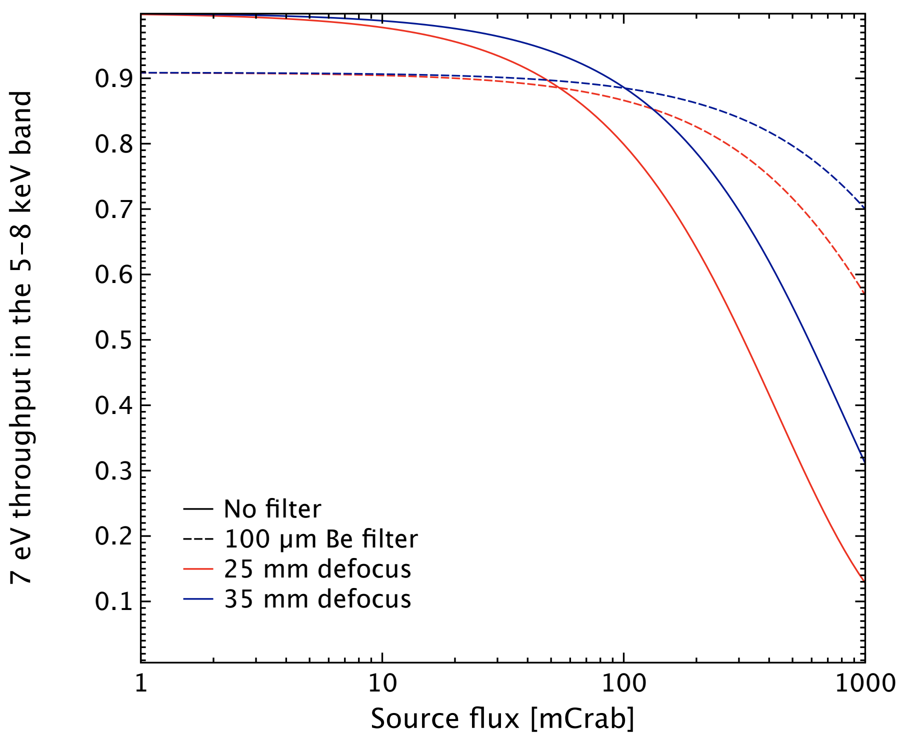
SIXTE describing, simulating, and analyzing complicated sources

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.	$\geqslant 7.9\,\mathrm{ms}$	$\geqslant 45.3\,\mathrm{ms}$	2.5 eV
(2) Medium res.	$\geqslant 7.9\,\mathrm{ms}$	$\geqslant 2.3\,\mathrm{ms}$	3 eV
(3) Limited res.	$\geqslant 7.9\,\mathrm{ms}$	$\geqslant 1.0\,\mathrm{ms}$	7 eV
(4) Low res.	$\geqslant 7.9\,\mathrm{ms}$	–	$\sim 30\,\mathrm{eV}$

Crosstalk in SIXTE

unintended transmission of information between signal channels

Different types of crosstalk:

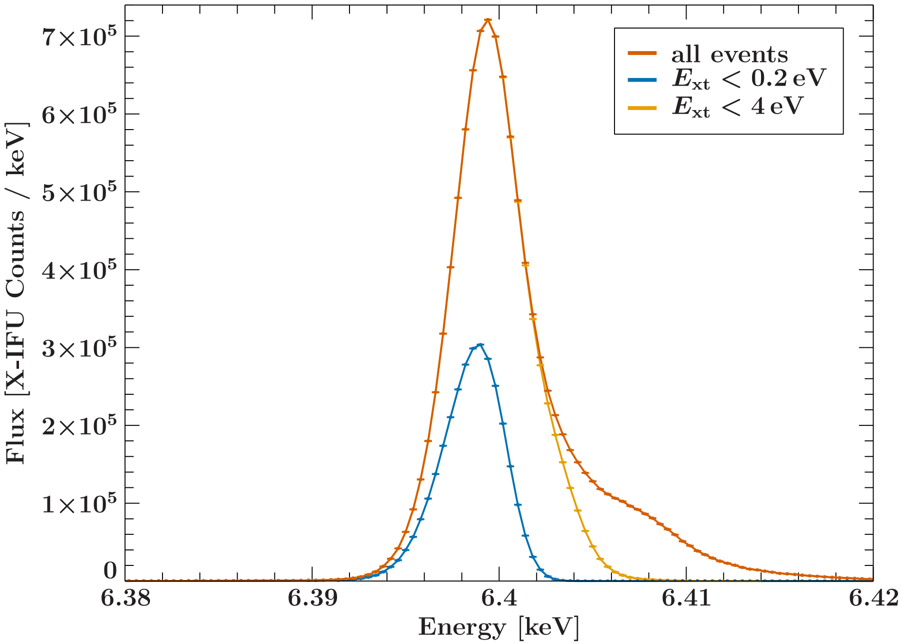
- thermal coupling of two pixels (physical neighbors)
- electrical coupling due to multiplexed readout (frequency neighbors)
- non-linear amplification of the read-out SQUID

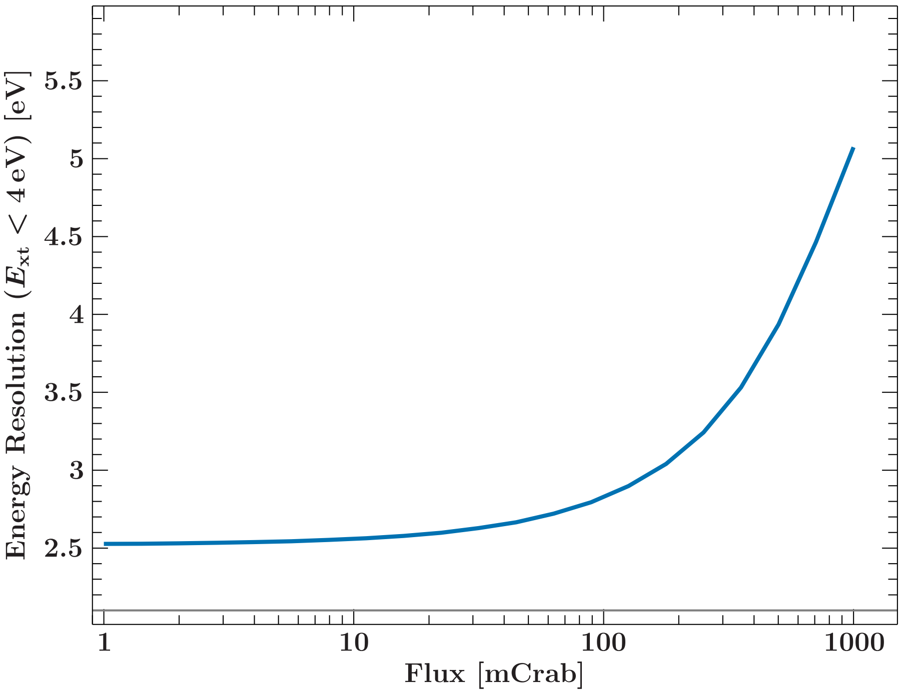
$\rightarrow$ implemented in SIXTE

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

Summary: The X-IFU with Sixte

- 3168 TES pixels in a hexagonal shape
- 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`