GPU Supported Simulation of Transition-Edge Sensor Arrays

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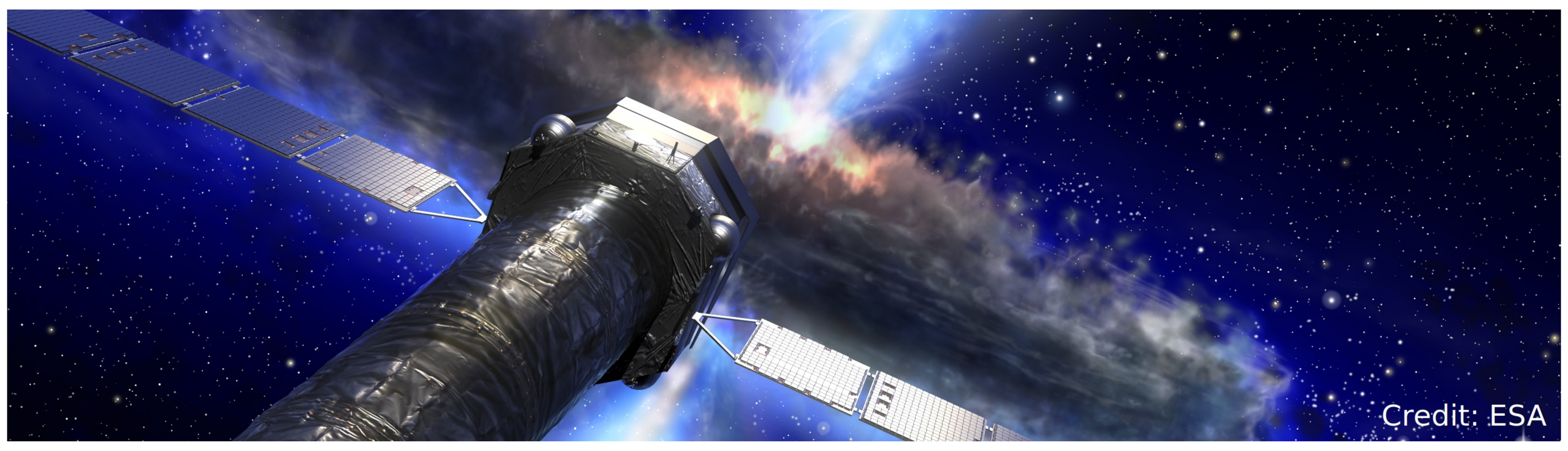
Abstract

We present simulation software utilizing graphical processing units (GPUs) for the physics of detectors based on arrays of transition-edge sensors (TES). With the support of GPUs it is possible to perform simulations of large pixel arrays, making the software a powerful tool in detector development. Comparisons with TES small-signal and noise theory confirm the representativity of the simulated data. In order to demonstrate the capabilities of this approach we present its implementation in `xifusim`, a simulator for the X-ray Integral Field Unit (X-IFU), a cryogenic X-ray spectrometer on board the future *Athena* X-ray observatory.

Introduction



- The X-IFU instrument on board *Athena* will operate a large array of more than 3000 TES pixels [1, 2]
- To study and optimize the instrument performance during design we are developing `xifusim`, a simulator of the X-IFU detection pipeline (C++, Linux/macOS)
- Here we describe our implementation of the first module in the simulation chain, a generic software for the simulation of TES pixel arrays under incident radiation

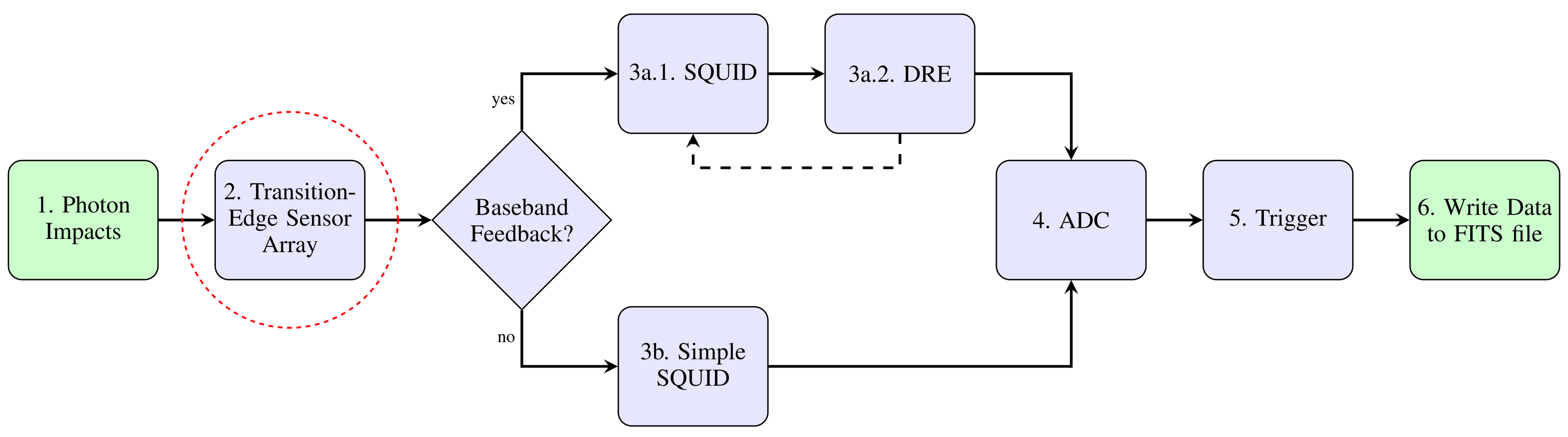


Figure 1: Data flow in `xifusim`. A list of photon impacts is propagated to the TES array where the pixel responses are calculated. Their signal is amplified in a set of SQUIDs, either using a simple, fast SQUID model or a model implementing the nonlinear SQUID response and baseband feedback. An Analog-Digital-Converter maps the measured current into a digital signal which is passed to a trigger that detects the individual pulses in the datastream and writes them to the output file.

Model Description

- We implement a generic mathematical model of the TES electro thermal system
- Evolution of temperature $T(t)$ and current $I(t)$ in a single TES pixel described by [3, 4]

$$C\frac{dT}{dt} = -P_b + R(T,I)I^2 + P_{in} \qquad (1)$$

$$L\frac{dI}{dt} = V - IR_L - IR_{TES}(T,I), \qquad (2)$$

- Modular code design: Individual parts of the model can be exchanged or refined as needed
- Here: Assuming linear resistance model for $R_{TES}(T,I)$ surface and power-law dependence for P_b

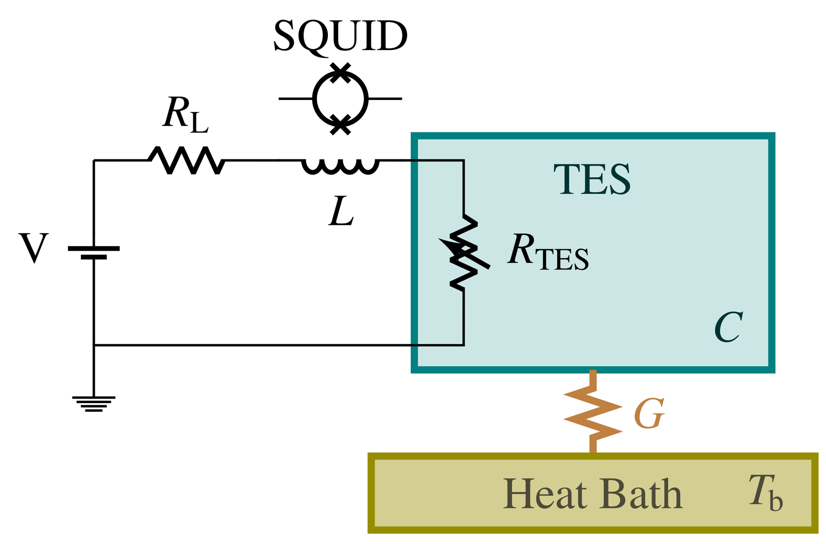


Figure 2: The TES model we implement in our software, consisting of the Thevenin-equivalent representation of the bias circuit coupled to the TES.

TES Array Simulation

- Input: Pixel parameters and list of photon impacts on the array
- Output: Current $I(t)$ in each pixel during simulation interval
- Code numerically solves Eqs. (1) and (2)
- Photon absorption modeled as delta-function impulse
- Simulation includes various noise sources, modeled as Gaussian noise

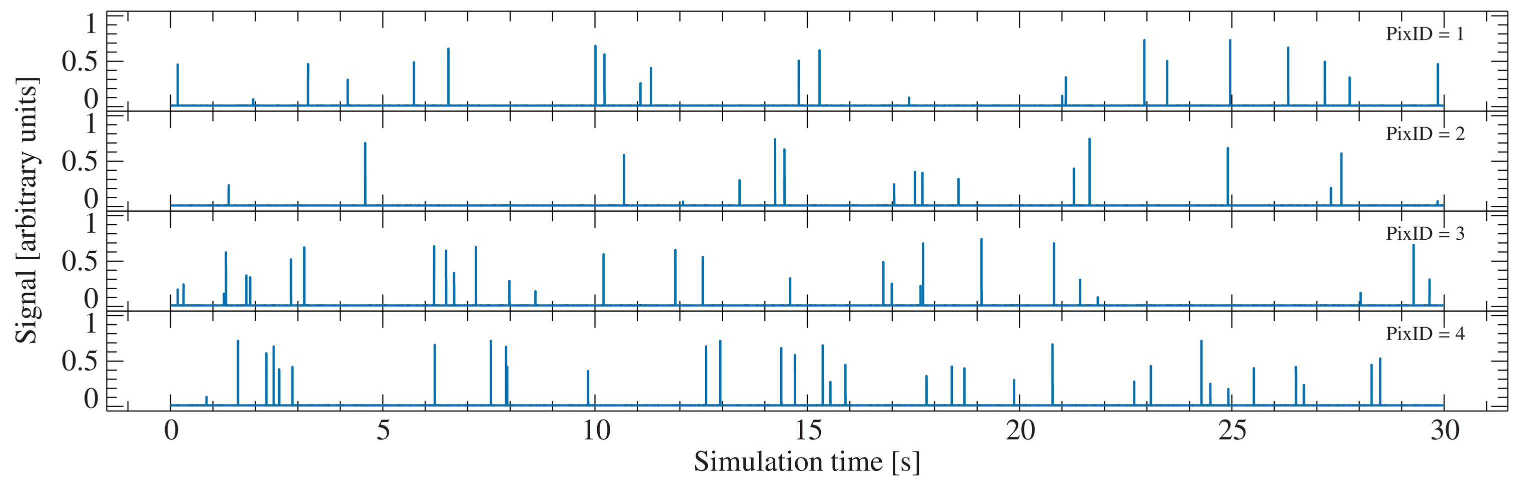


Figure 3: Individual signals of a four pixel configuration during a 30 seconds simulation with random impacts, using the current best estimate X-IFU pixel parameters. Currents are flipped and normalized.

GPU Implementation

- Run time on single-core processor sufficient for small array simulations and short time intervals
- To enable long simulations for large arrays with thousands of pixels like the X-IFU we also implement a GPU accelerated version of the code using the Nvidia CUDA platform [5]

⇒ Speedup by factor 3000 for full array - now five times faster than real-time

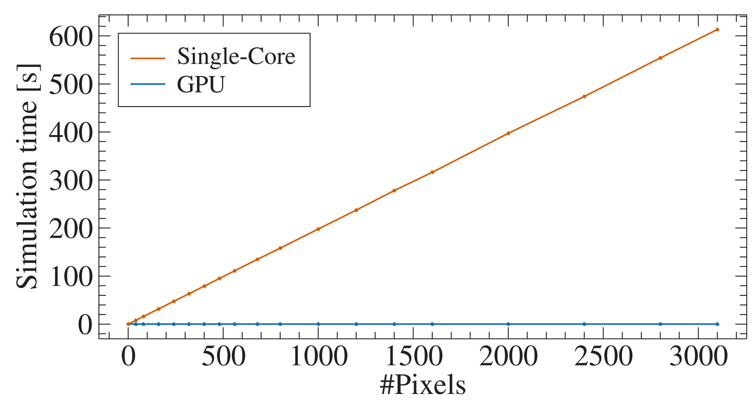


Figure 4: Run time comparison between single-core and GPU accelerated version on an Nvidia GeForce GTX 1080 Ti for different array sizes simulated for one second each.

Verification of the Simulation Output

- Started investigating different means to verify our simulation output
- Power spectral density of current noise in simulation matches theoretical levels derived with linear equilibrium ansatz [3]
- We also find good agreement with small-signal approximation [3] of Eqs. (1) and (2) for low photon energies
- Comparisons with measured data will be performed next

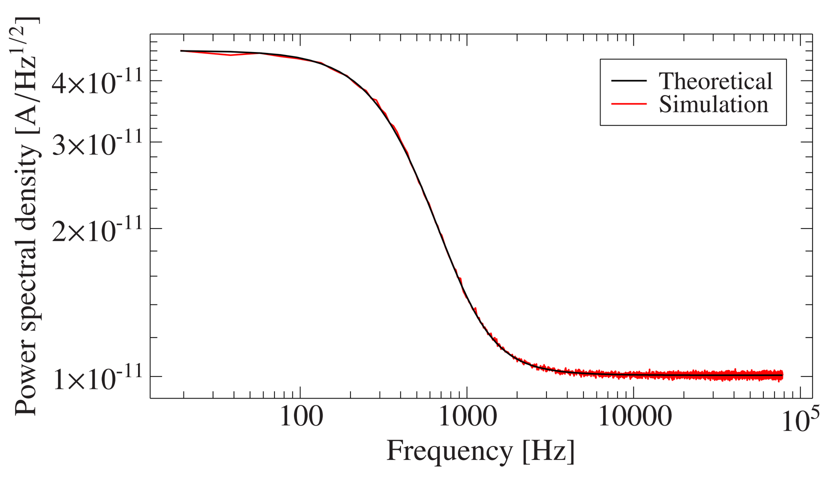


Figure 5: Comparison between predicted and simulated noise levels. Included noise sources are Johnson noise of the TES and load resistor, thermal fluctuation noise and noise from the bias line.

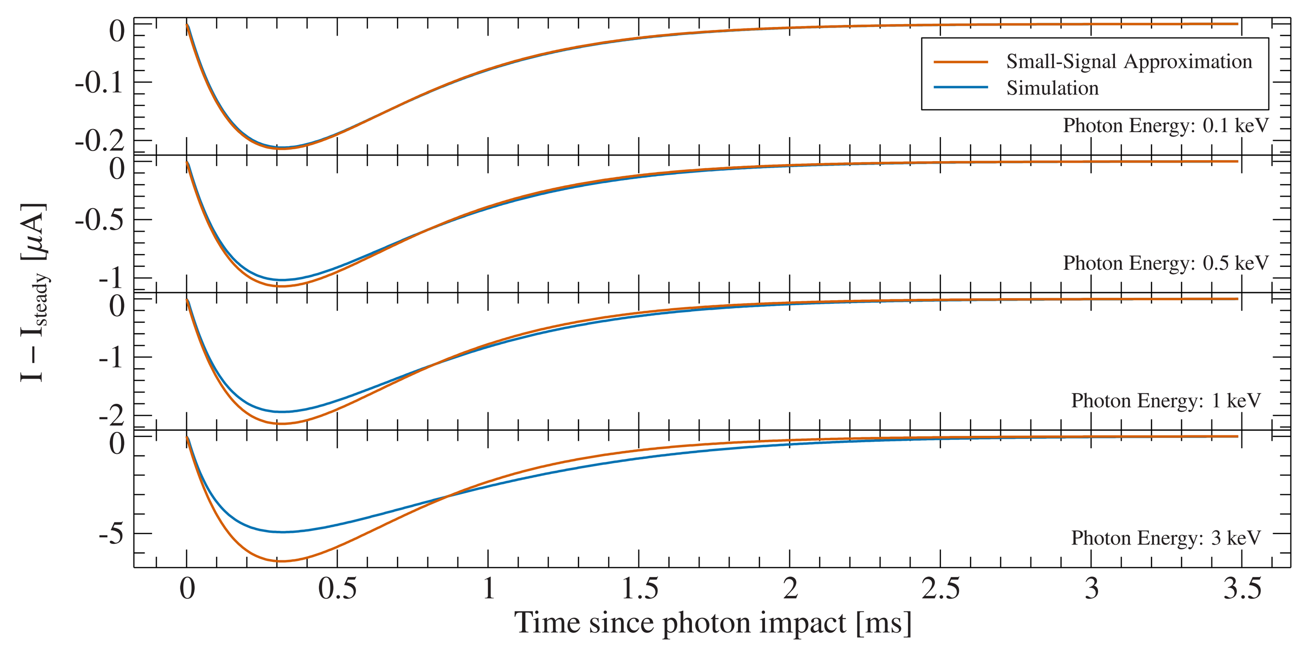


Figure 6: Pulse shape comparison between simulation and TES small-signall model [3] for different photon energies. The pulses match very well for small energies. For higher energies they start to deviate as expected due to the non-linearities in the system.

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References

[1] D. Barret, T. Lam Trong, J.-W. den Herder, et al., *Proc. SPIE* **10699**, 106991G, (2018), DOI:10.1117/12.2312409.
[2] K. Nandra, D. Barret, X. Barcons, et al., *arXiv:1306.2307*, (2013).
[3] K.D. Irwin and G.C. Hilton, *Topics Appl. Phys.* **99**, 63-149, (2005), DOI:10.1007/10933596_3.
[4] J. Wilms, S.J. Smith, P. Peille, et al., *Proc. SPIE* **9905**, 990564, (2016), DOI:10.1117/12.2234435.
[5] J. Cheng, M. Grossmann, and T. McKercher, (2014), John Wiley & Sons, Indianapolis.

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