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Centre for Advanced Instrumentation

Real-time pixel data processing from energy-resolving detectors.

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Real-time resonator data processing from MKIDS

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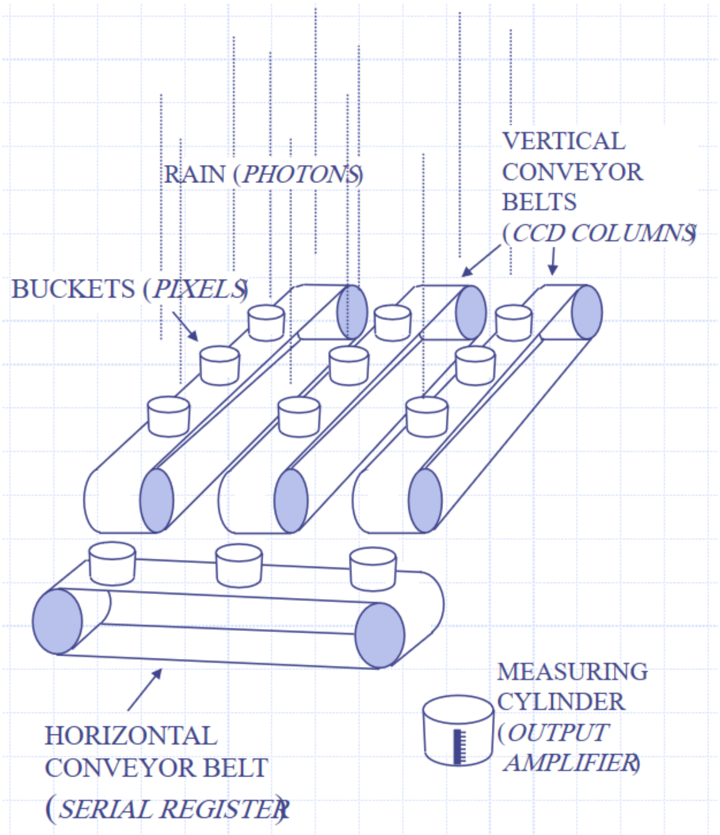
Contents

- What are MKIDS
- History of data processing of MKIDS
- FPGA, CPUs and GPUs
- How does this effect the RTC
- Future…

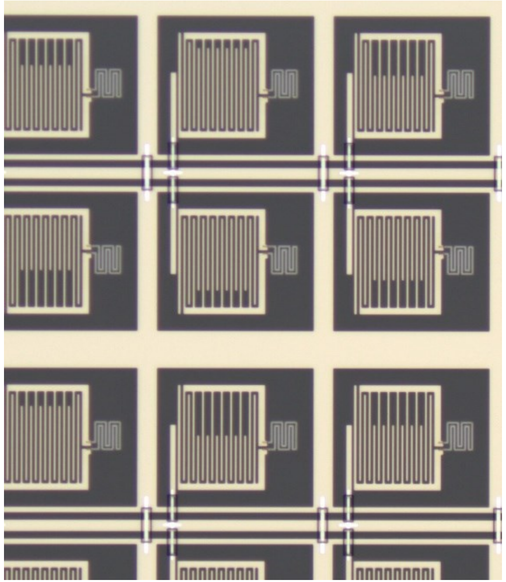
The CCD bucket

- CCDs collect data over time, then readout in full.
- Fixed integration time.
- Temperature
  - 100+ k

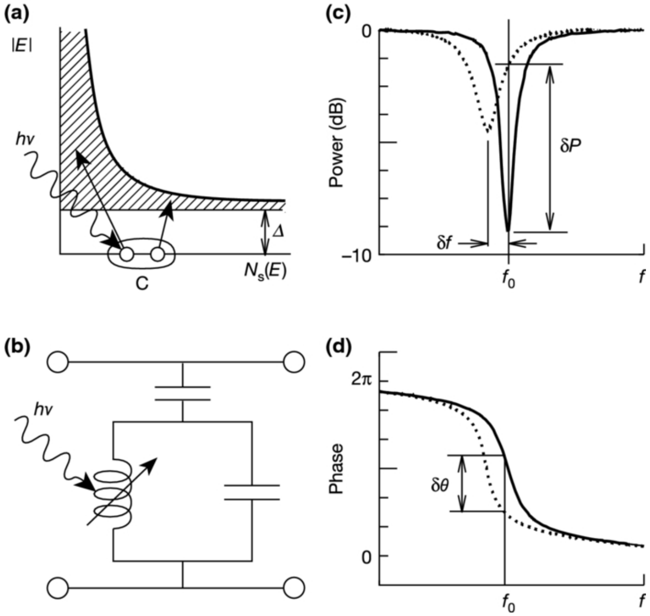


CREDIT: From: slideplayer.com/slide/4990634/

MKIDs - Microwave Kinetic Inductance Detectors



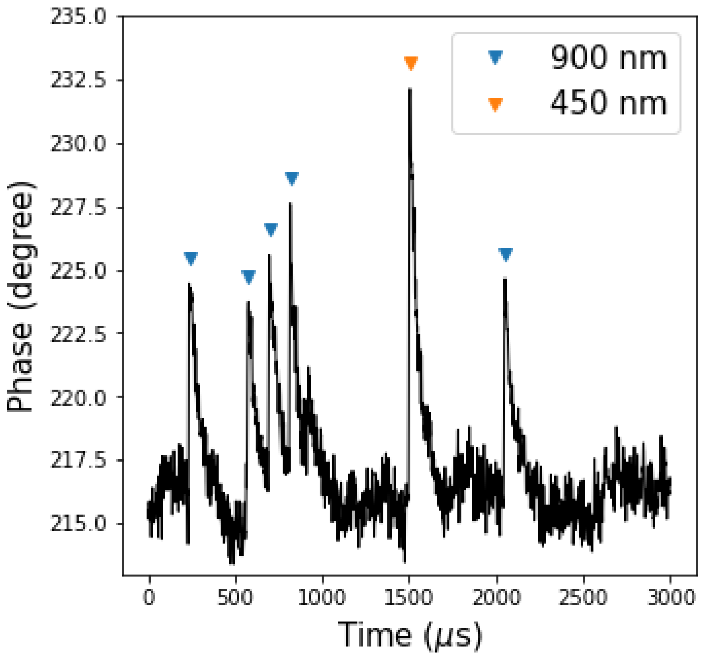
CREDIT: www.sron.nl



CREDIT: MKIDs readout: McHugh et al. 2012, "A readout for large arrays of microwave kinetic inductance detectors" Rev. Sci. Inst., 83, 044702

Photon detection

- Resonators phase measured at 1 MHz.
- Photon energy and wavelength retrieved from integrated phase.
- Matched filter used to detect these arrivals.
- Detection bandwidth demonstrated 400 nm to 1500[1] nm but no technical limits to go beyond



[1] De Visser et al., 2021, DOI : 10.1103/PhysRevApplied.16.034051

Energy resolution

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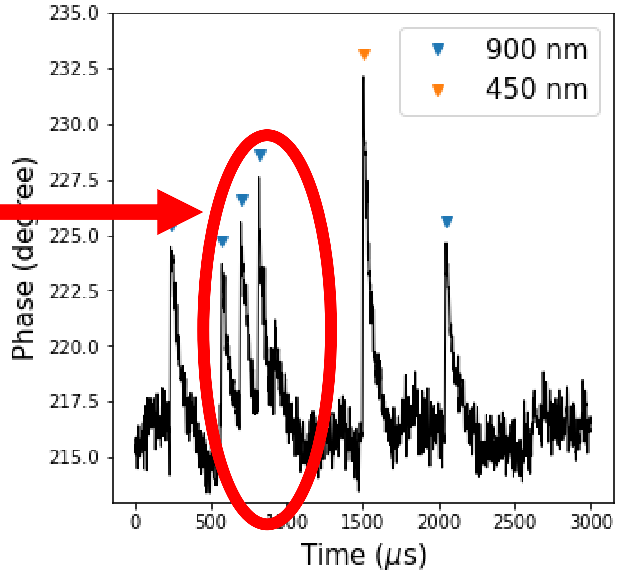
Photon → Pulse → Amplitude ? → Energy !

Saturation

- Pulse sampling insufficient
  - Measure uncertainty
  - Number of photon confusion (1 at high energy instead of 2)



Photon counting rather than full frames.

- Readout provides
  - Photon wavelength/energy
  - Which resonator
  - Time stamp
- Every photon separately.
- These can be buffered into packets of N photos or sent individually depending on use case.

Gen 1 - Casper Roach 2011

Credit: Techneinstruments.com

UC Berkeley's CASPER (**C**ollaboration for **A**stronomy **S**ignal **P**rocessing and **E**lectronics **R**esearch)

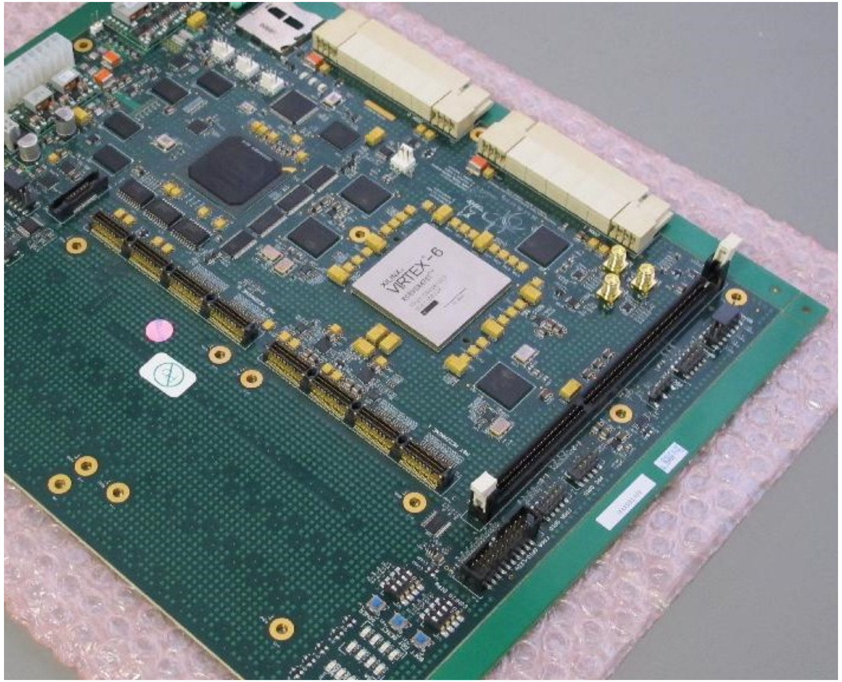
ROACH (**R**econfigurable **O**pen **A**rchitecture **C**omputing **H**ardware) board family

Mainly used for radio astronomy

- Xilinx Virtex-5
- Add on boards for ADC DACs.
- Provides Matched filter and sends 1 packet per photon via ethernet.
- Up to 256 resonators supported.

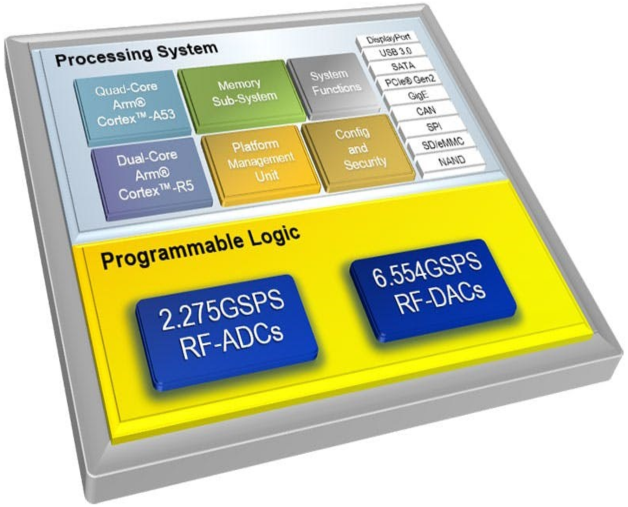
Casper Roach2 2015

- Xilinx Virtex-6
- More resources allow more ‘pixels’.
- Up to 1K resonators
- 10 GbE networking.



Credit :Durham University

Xilinx(AMD) Radio Frequency System-on-Chip(RFSoC) FPGA



CREDIT: www.xilinx.com

- Built-in APUs(PS: Processing System) enabling a neat firmware solution;
  - Complete application system;
  - DDR RAM
  - Ethernet interface
  - UART
- Built-in RF ADCs and DACs making the RF implementation smaller, cheaper and easier;
  - ADC 12bit 4.096Gsps x8
  - DAC 14bit 6.554Gsps x8

Xilinx

- Onboard processing
  - 2k resonators
- Stream data onwards:
  - 8k resonators
- Output 32 Gbit/s
  - 2x 25 GbE networks.

- 240 x 240 detectors
- On board processing
  - 30 FPGA boards required.
- Streaming.
  - 8 FPGA boards required.

Xilinx

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<u>For comparison</u>

Roach 1

225 boards

Roach 2

57 boards

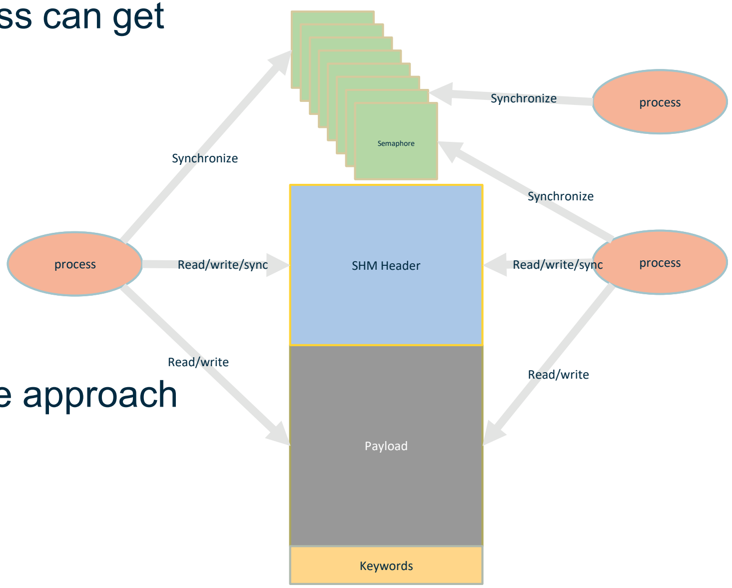
Moving FPGA to Servers for photon detection

- Latest FPGA more ADC and DAC but not enough resources for pulse detection on board.
- Complex to program requiring specialist FPGA engineers.
- Move to server based (CPU or GPU)
  - Allows more accessible programming for scientists.
  - Off the shelf hardware
  - Cheaper.
  - Faster development

How many servers what hardware?

DAO

- Processes are completely independent
- Data are all shared with the same format, any new process can get access to everything always the same way
- Fast and simple read write access
- Easy to synchronize
- C/C++/Python and more to come (Matlab)
- GPU/CPU compatible
- Distributed (scalable)
- Biggest advantage of DAO is its flexibility and easy to use approach
- All the data are available at all time, from any language
- Timing information and synchronization tools available



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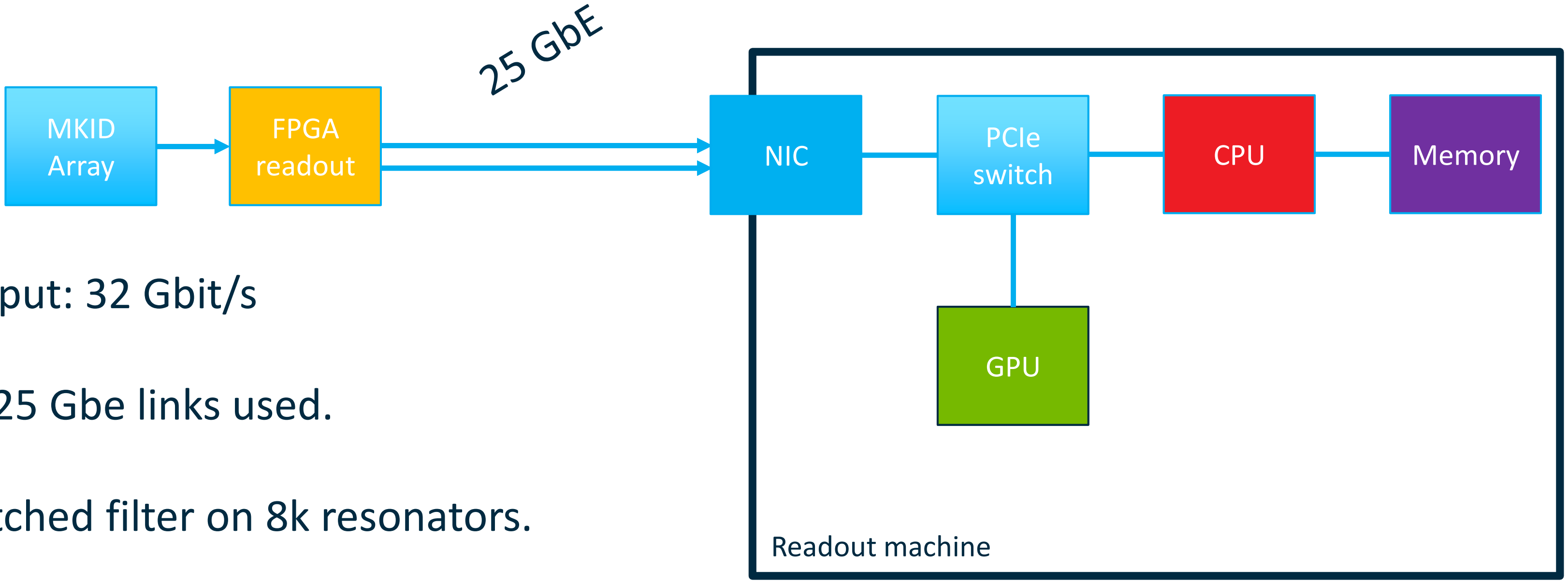
MKID Photon detection on servers.



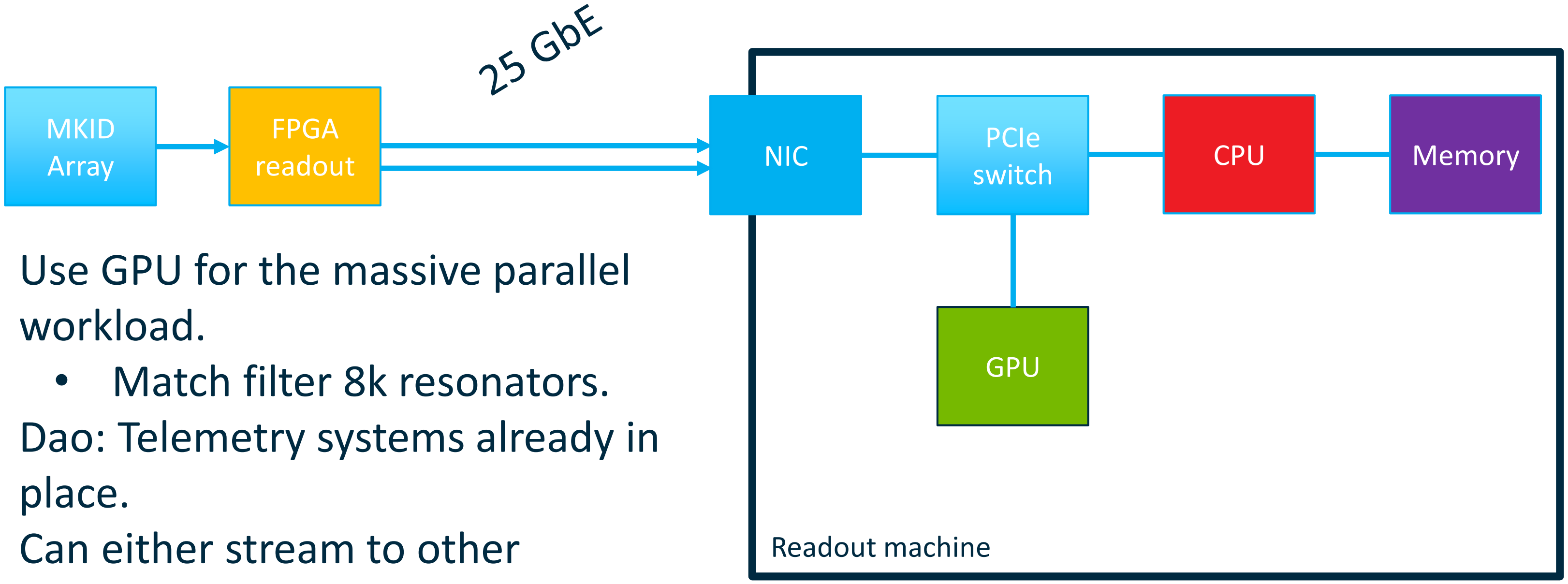
Output: 32 Gbit/s

2 x 25 Gbe links used.

Matched filter on 8k resonators.

GPU or CPU

GPU for matched filter



- Use GPU for the massive parallel workload.
  - Match filter 8k resonators.
- Dao: Telemetry systems already in place.
- Can either stream to other hardware or continue RTC within server depending on resources.

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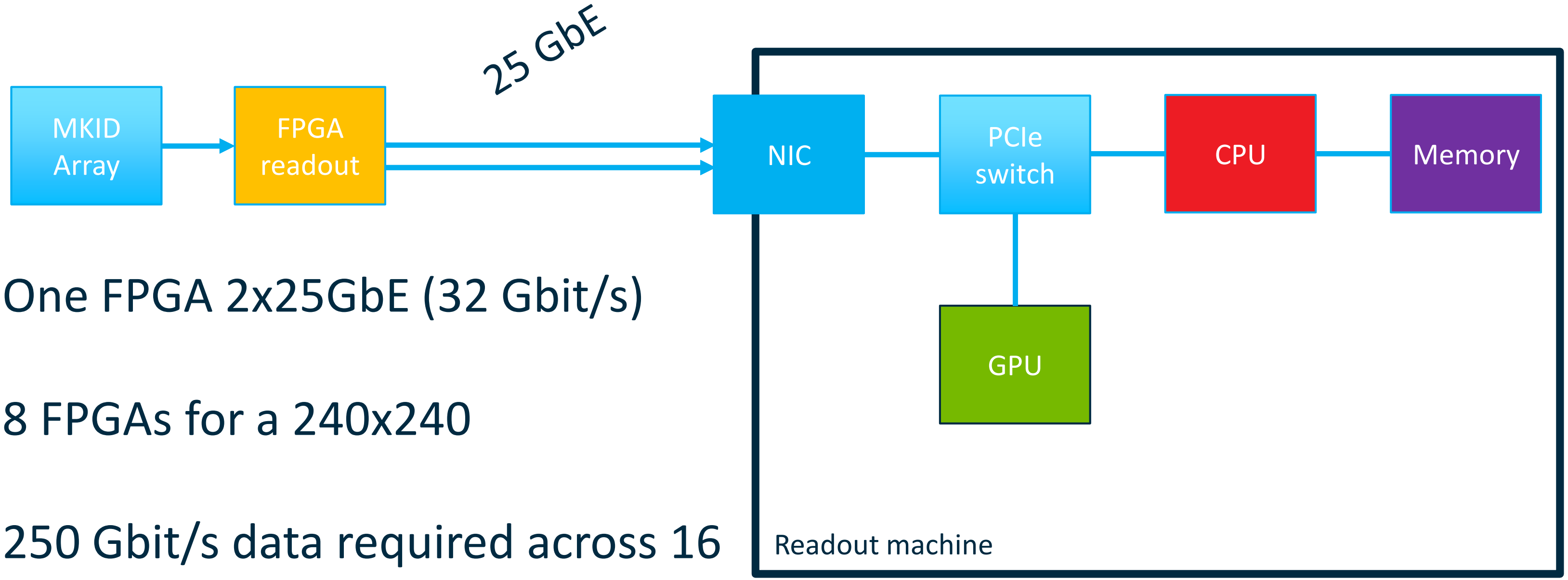
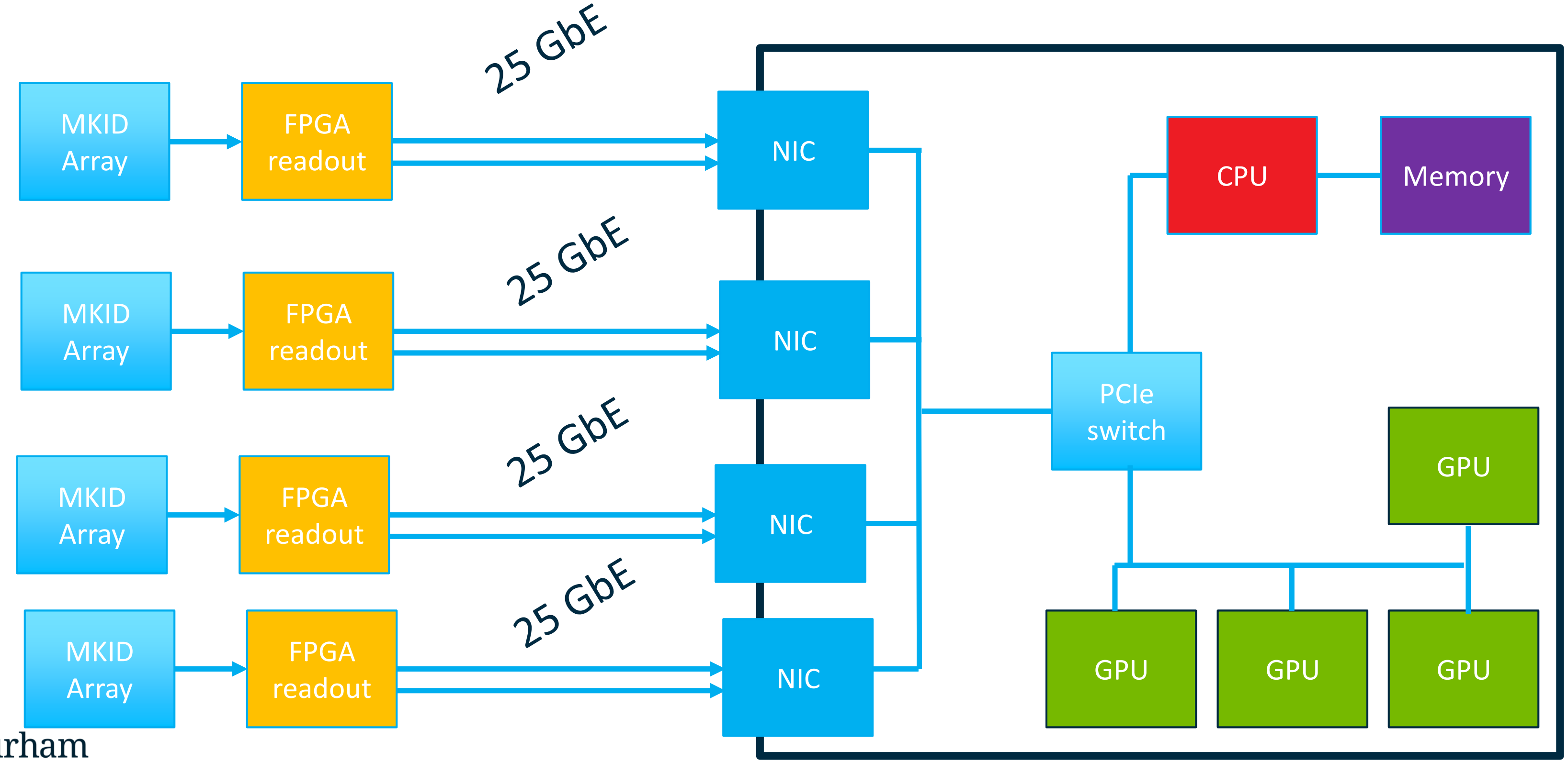
Prototype

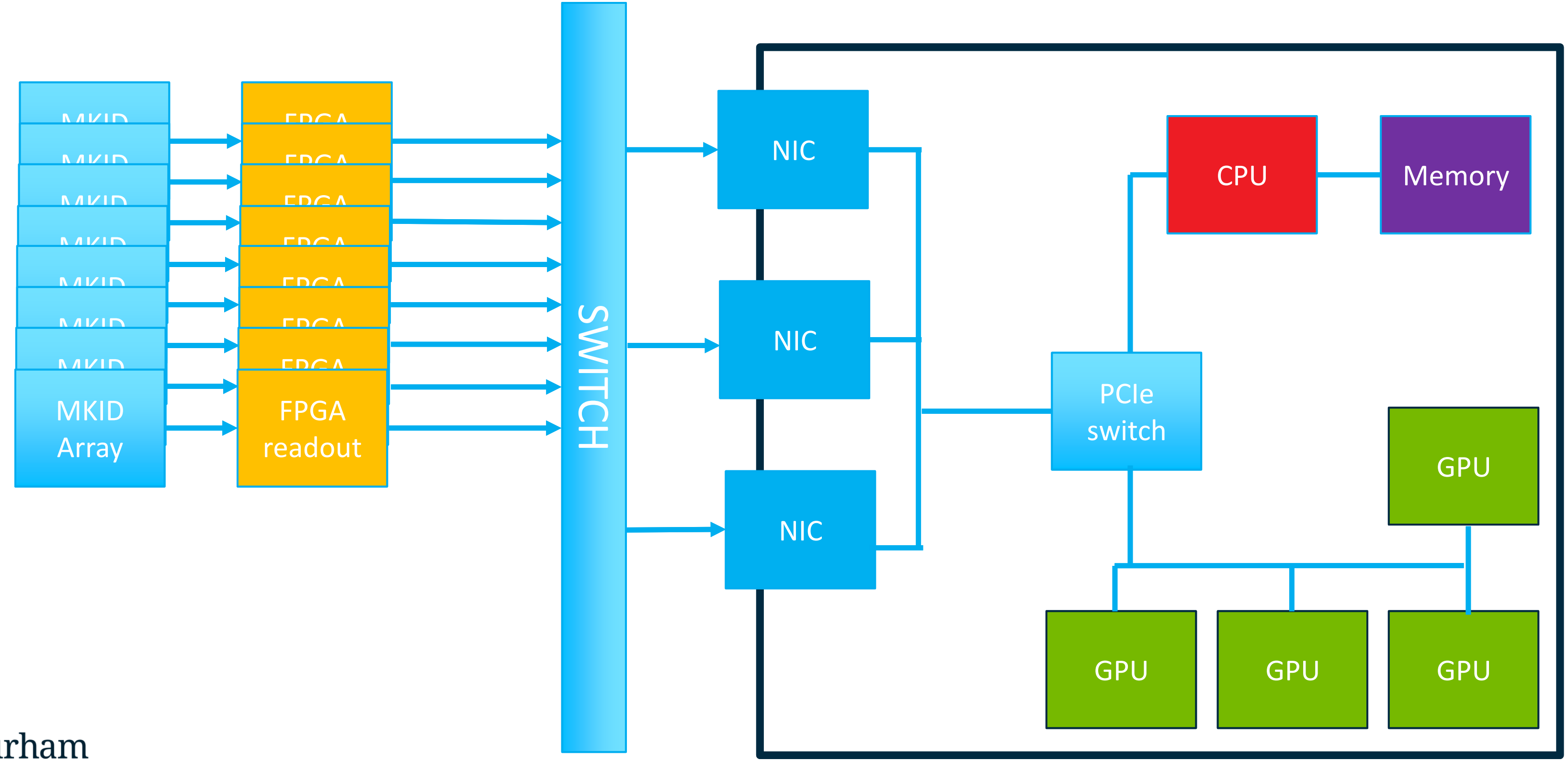


- One FPGA 2x25GbE (32 Gbit/s)
- 8 FPGAs for a 240x240
- 250 Gbit/s data required across 16 25 GbE links from FPGA

MKID readout?



MKID readout?



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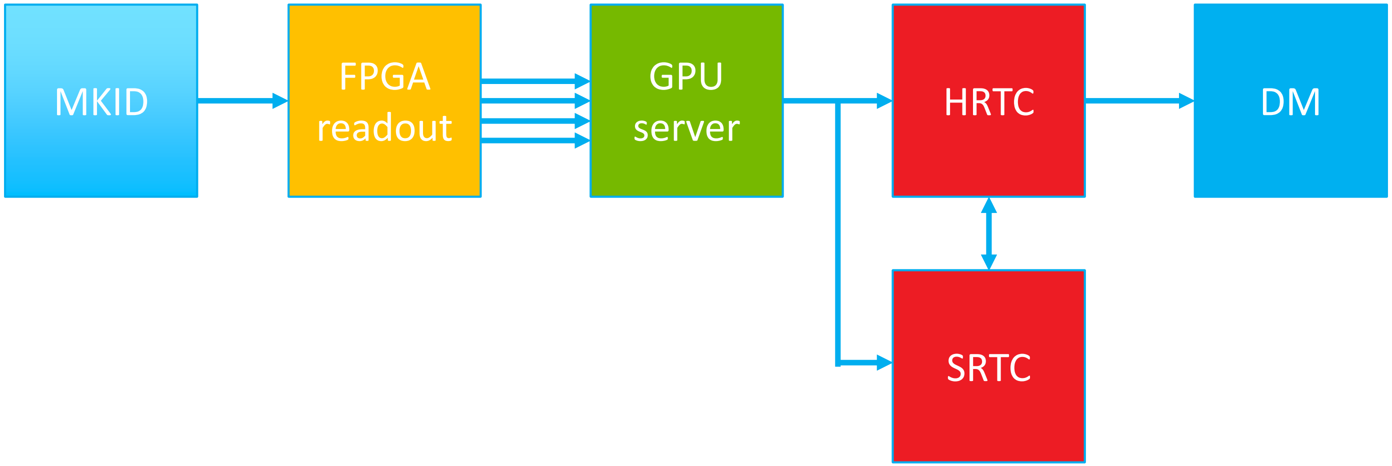
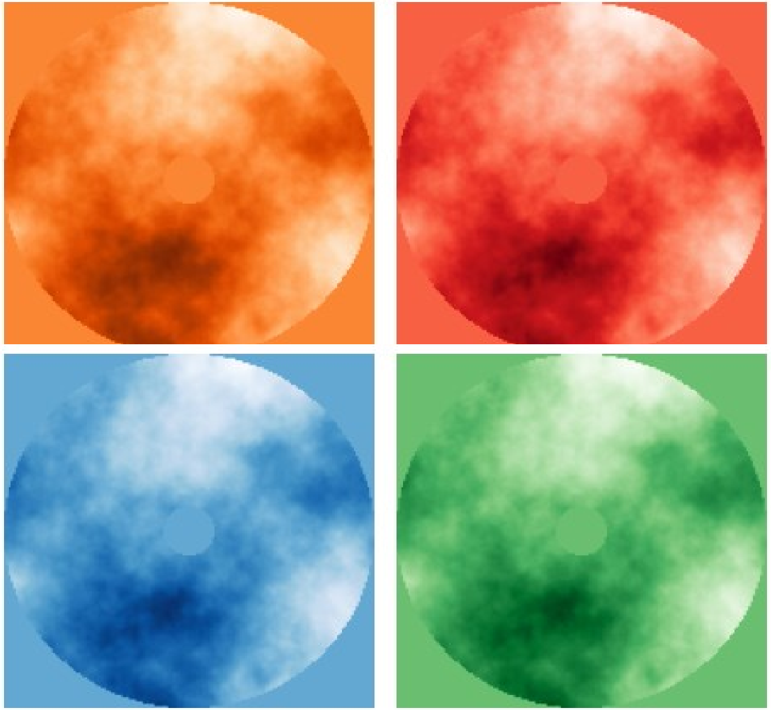
First pass at an MKID RTC

- Traditional RTC for proof of concept.



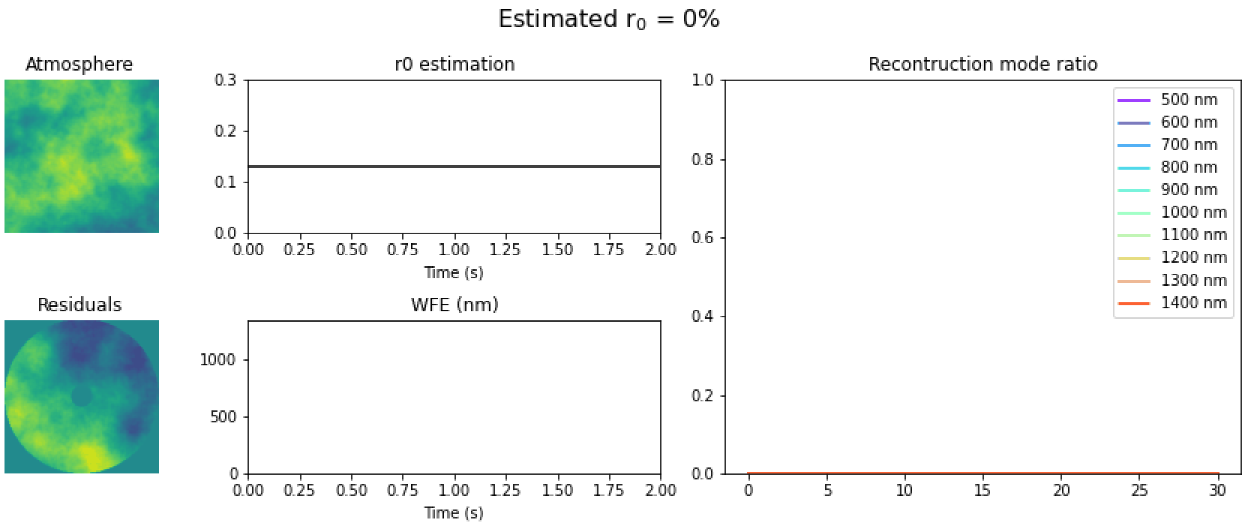
Possibilities for investigation.

- Hyperspectral wavefront sensing
  - Optical gain tracking and r0 estimation.
- Adaptive integration times.
- Chromatic super resolution
- Pupil dispersion : widening the useable bandpass



Estimate R0 with hyperspectral wavefront sensor.

Simulation parameters
8 m telescope
500 modes
40 subapertures



*See Aurelie Magniez AO4ELT preceding's for more information

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Adaptive frame times

- Frame times based on flux.
  - New frame every 100 photons use last 1000.

- Compensate different wavelengths at different rates.

What else will this unlock?

Thanks for listening

CFAI Recruitment

Current/closed

- Postdoc MKID + AO (deadline 5th)
- Assistant Optical Engineer (deadline 10th)

Upcoming

- post docs in AO focuses on RTC
- graduate software engineer roles.

Website, talk or email me for more information

https://www.durham.ac.uk/job-vacancies/
david.barr@durham.ac.uk

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