The Future Program of ESO Detector System Group in the ELT Era

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IR Detection Workshop, 7 – 9 June 2023, Toulouse

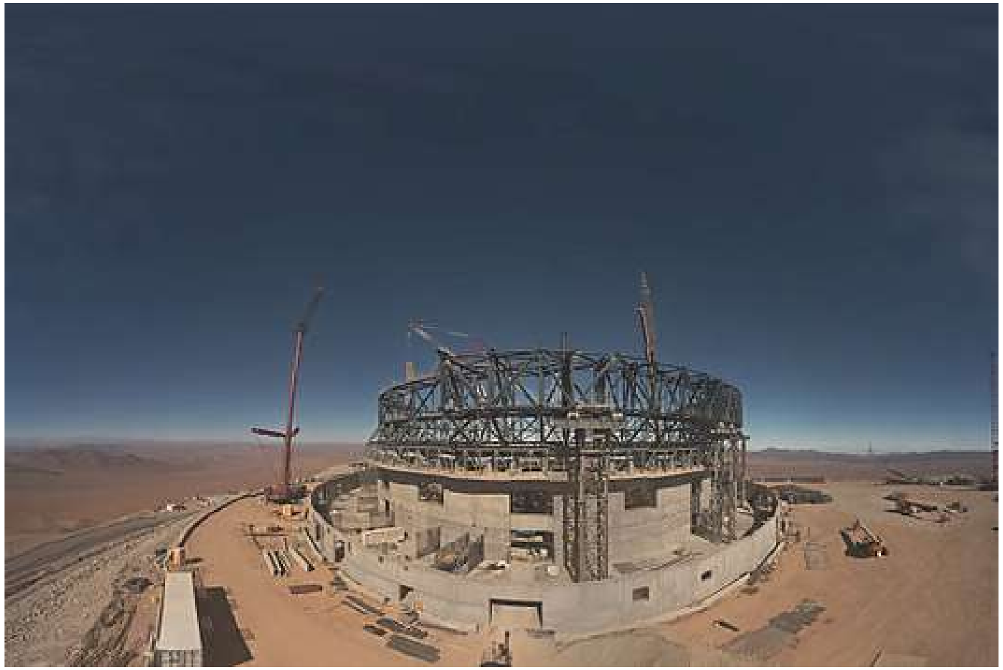
Overview of Presentation

- First Generation ELT Instruments
- Detector Systems
- ELT Detector Characterisation Facilities
- Buffered Output Operation and Glow Issue
- Dark and Noise Performance
- Persistence Correction
- Special Read Modes
- Controller Developments at ESO
- NGCII Controller Architecture
- NGCII for IR/CMOS detectors
- Prototype Boards of NGCII
- NGCIIs for ELT and Future VLT Instruments

ELT Current Status

Artist's view of ELT

Current status of ELT construction as of 2nd June 2023

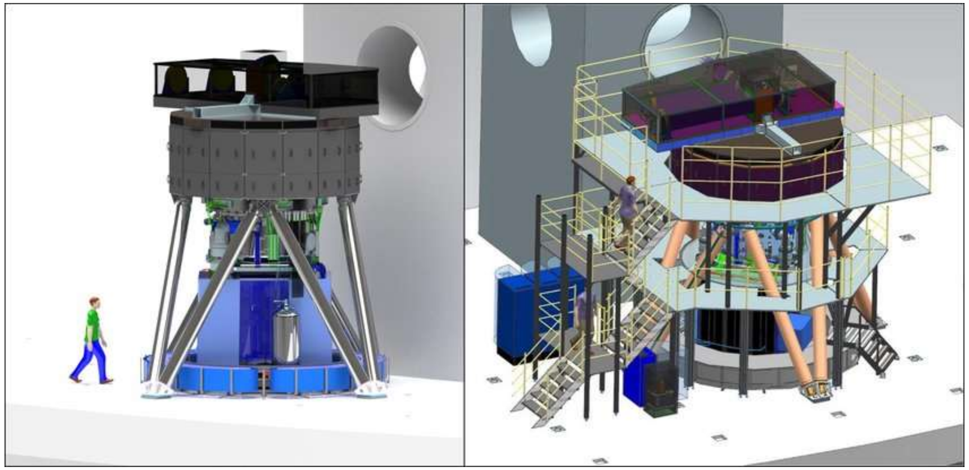


ELT | ESO

First Generation ELT Instruments

MICADO - Multi-AO Imaging Camera for Deep Observations

- First light Imager on ELT, lead by MPE
- Standard imaging, Astrometry, High contrast imaging, Spectroscopy
- Similar sensitivity to JWST, but 6x resolution



MICADO | ELT | ESO

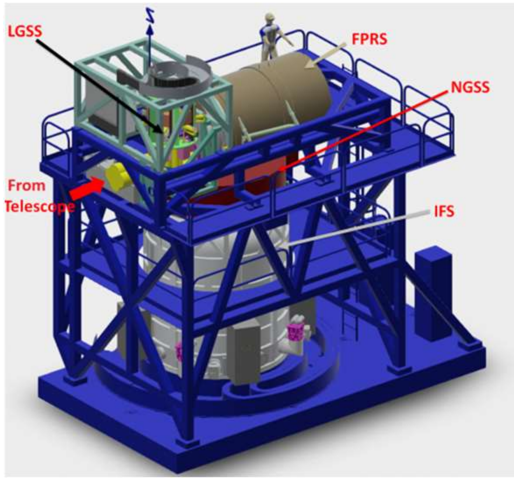
Detector System for MICADO

- 3x3 Mosaic of H4RG-15, 2.5µm
- 82K – 85K operating temperature
- 200kHz pixel rate, 32 channel operation, Central detector with 64 channels

First Generation ELT Instruments

HARMONI - High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph

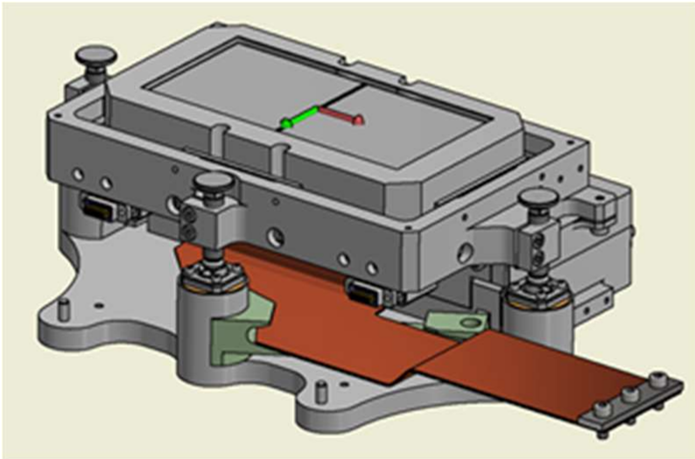
- Workhorse 3-D spectrograph, lead by Oxford
- IFU with image slicer
- LTAO/SCAO corrected field with various spatial and spectral settings



HARMONI | ELT | ESO

NIR Detector Systems for HARMONI

- 4x IFU NIR spectrographs, each containing 2x1 H4RG-15, 2.5um cut-off detectors
- 40K operating temperature
- 64 channel operation



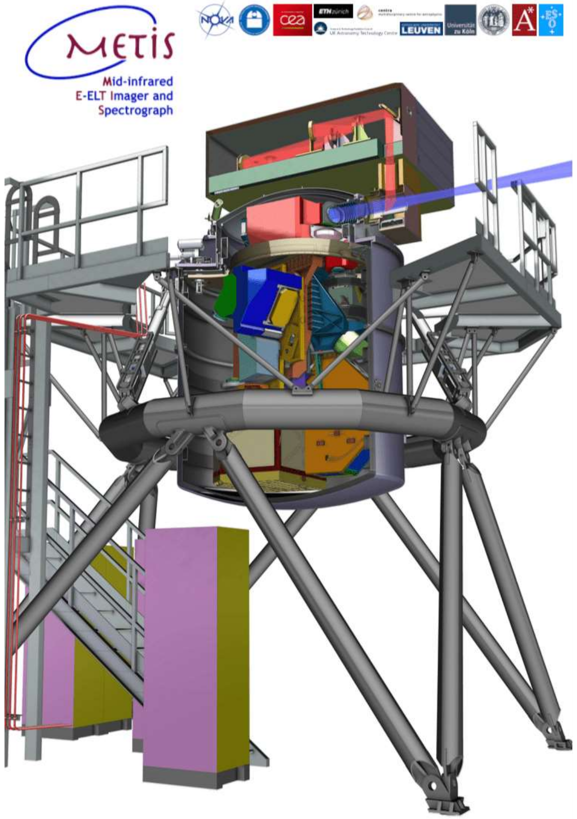
First Generation ELT Instruments

METIS - Mid-infrared ELT Imager and Spectrograph

- Direct and high contrast imaging
- Long slit and IFU spectroscopy
- High resolution spectroscopy (R~100k)
- Imager SCAO corrected (11”x11” FoV)

Detector Systems for METIS

- 1x H2RG (5.3um) for L-M band imager
- 4x H2RG (5.3um) for L-M band spectroscopy
- 1x GEOSNAP for N band imaging, coronography
- SAPHIRA detector for SCAO



METIS | ELT | ESO

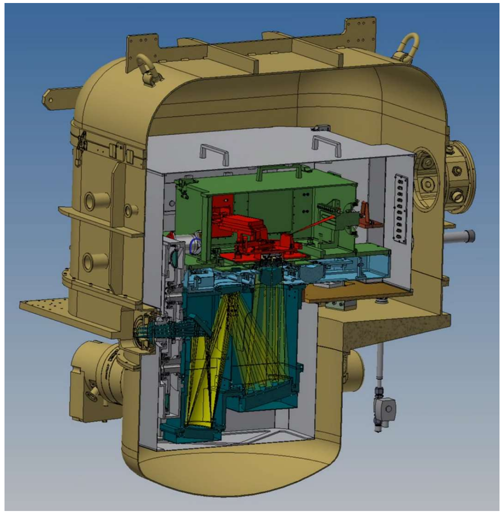
ELT Detector Test Facilities

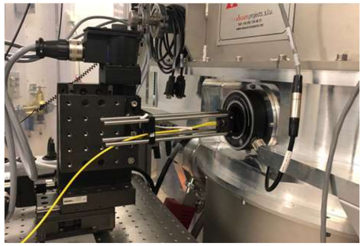
FIAT - Facility for Infrared Array Testing

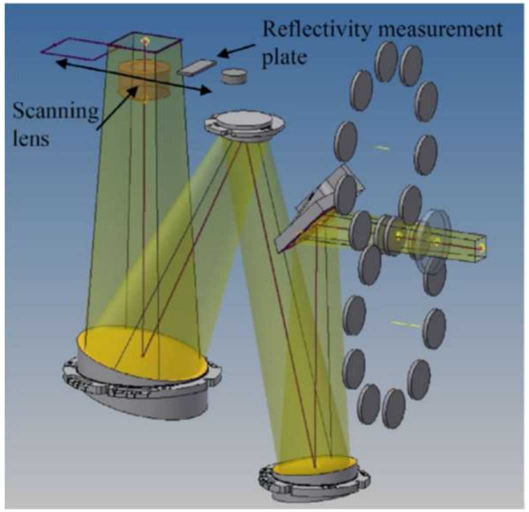
- 17 x H4RGs to be characterized
- Detector operating temperature range 40K to 110K
- Low background, Easy access

FIAT - Optomechanical Layout

- Conjugated object image focal plane, field of view ~66mm square
- QE measurements, Intra-pixel scan







Bezawada, N., George, E., Ives, D., et al. 2023,Astron.Nachr./AN,e20230061.

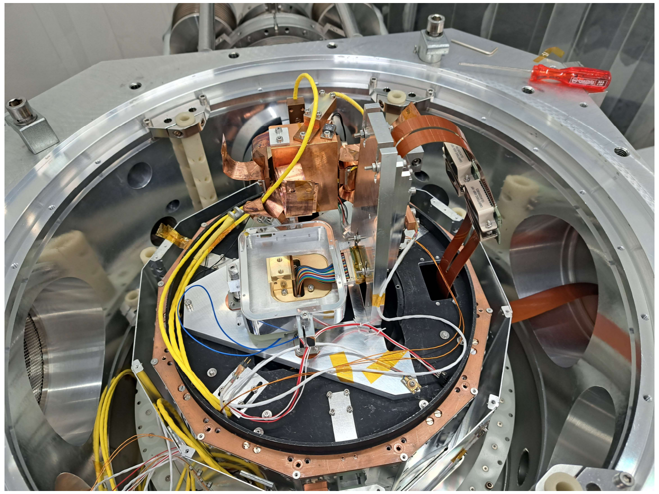
ELT Detector Test Facilities

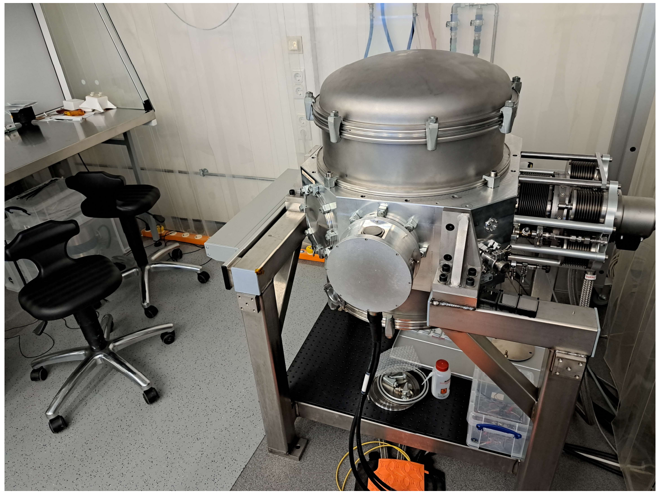
MTF – Mosaic Test Facility

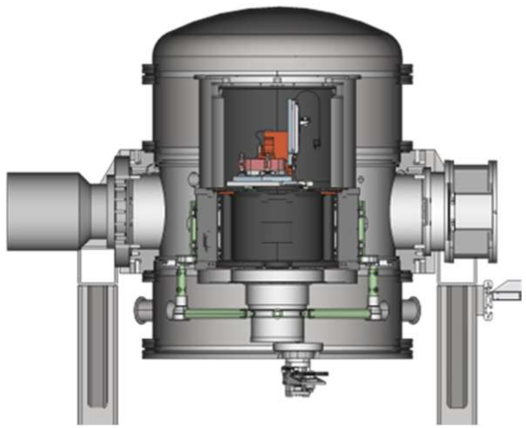
- Detector operating temperature from 35K to 110K
- Low background, no window, easy access.

MTF Features

- Filters (J, H, K, L, M)
- Cryogenic blackbody (up to 340K when cryostat cold)

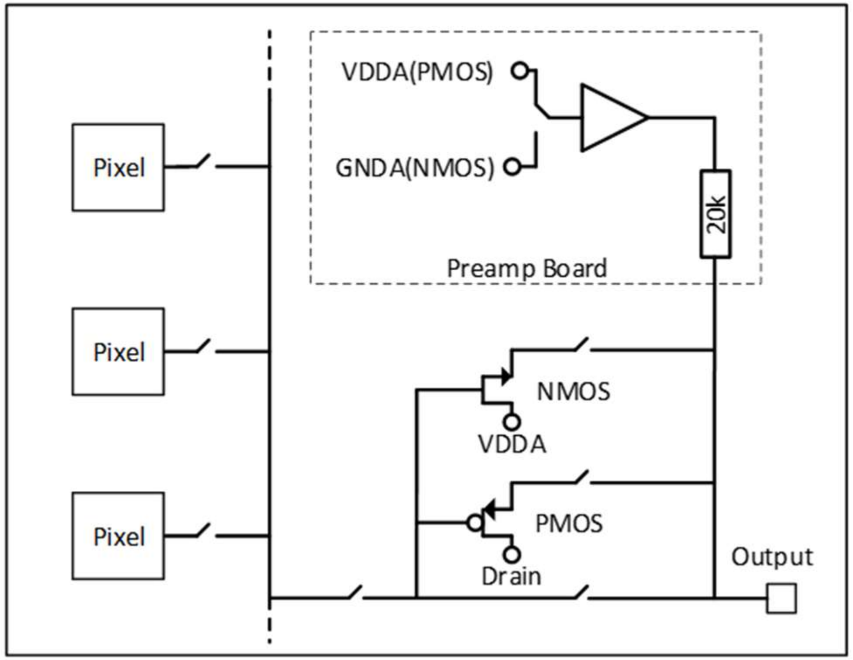






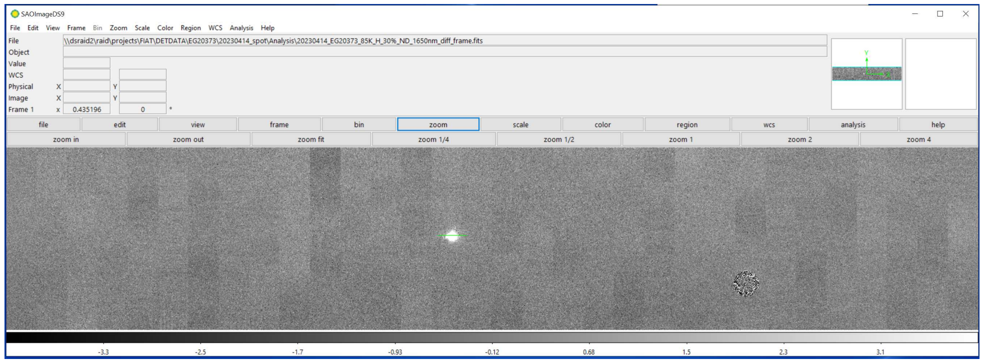
H4RG Buffered Slow Read Mode

Output modes of H4RG detectors



Advantages of buffered output mode in slow speed

- Higher readout rates (~300kHz)
- Better SNR for short integrations
- Low output impedance, Negligible electrical crosstalk
- Higher output drive capability, low unit cell currents



[Bezawada, N. et al., Performance advantages of buffered output mode operation of HxRG near infrared detectors, SPIE-114543J (2020)]

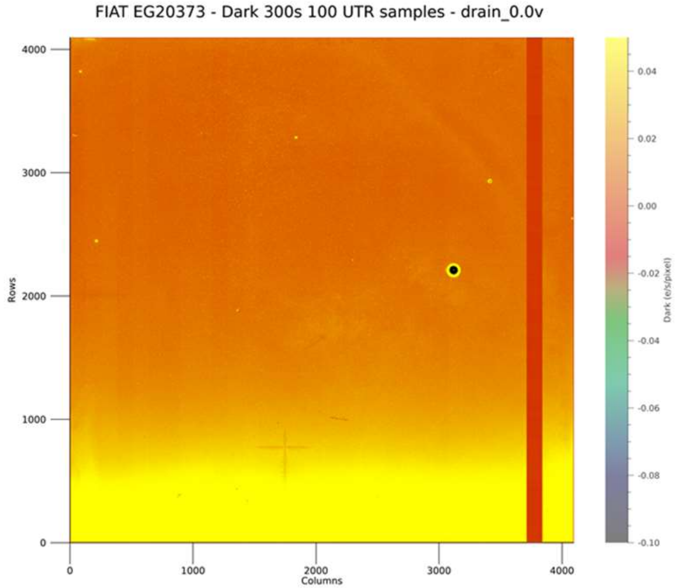
H4RG Output Buffer Glow

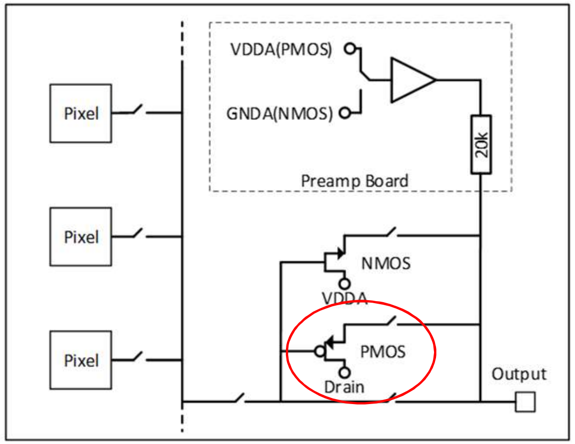
Output buffer glow – output source follower drain at 0.0V

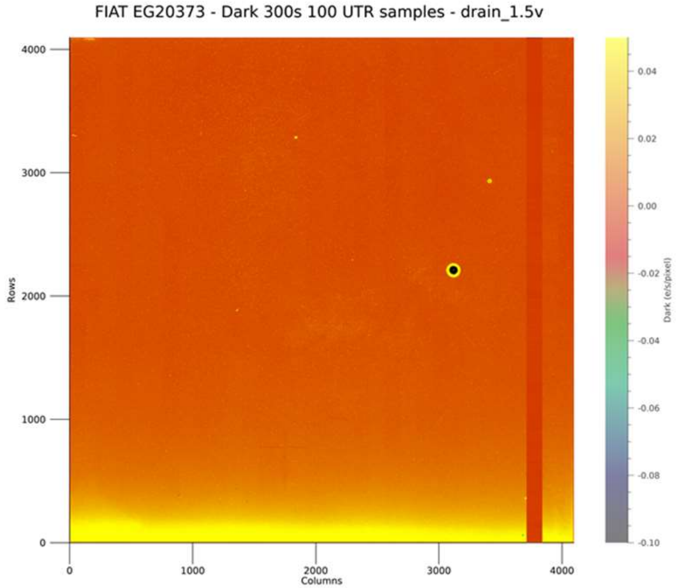
- A few hundred rows at the bottom are affected by the glow

Output buffer glow – output source follower drain at 1.5V

- Higher drain supply reduces the glow significantly



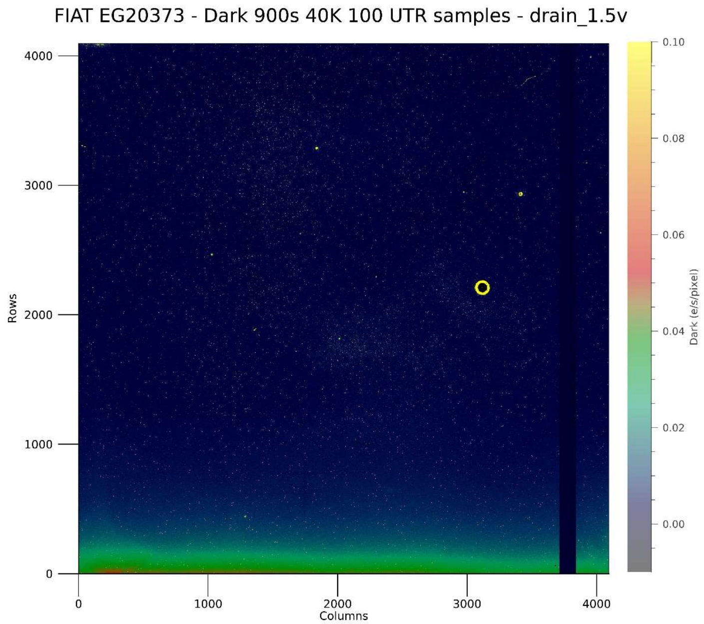


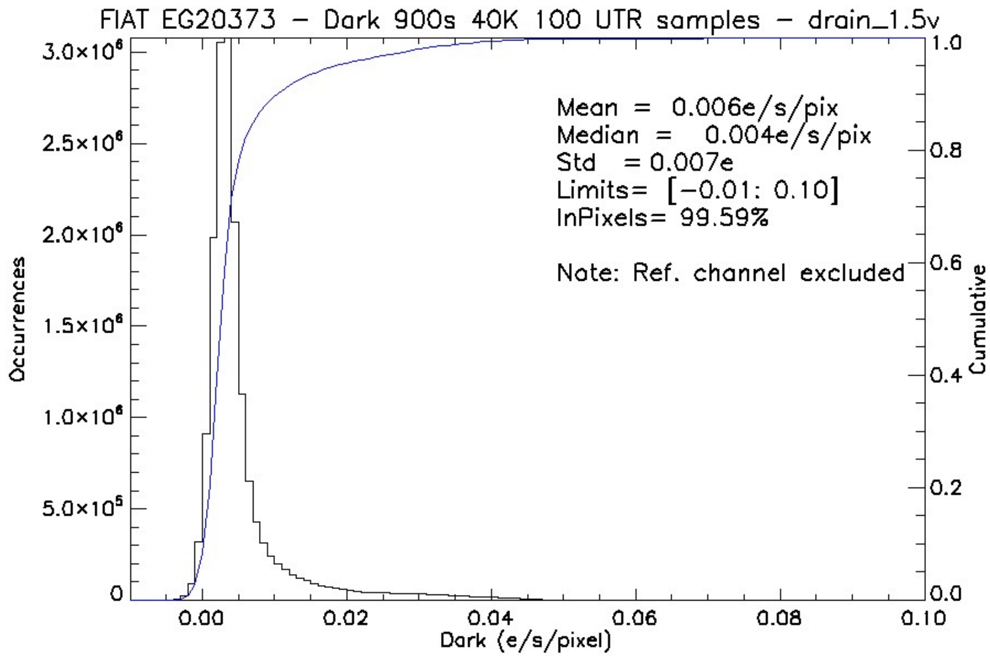


H4RG (EG) Dark Performance

Dark measured from 900s at 40K, 100 UTR samples, avg. of 20 DITs

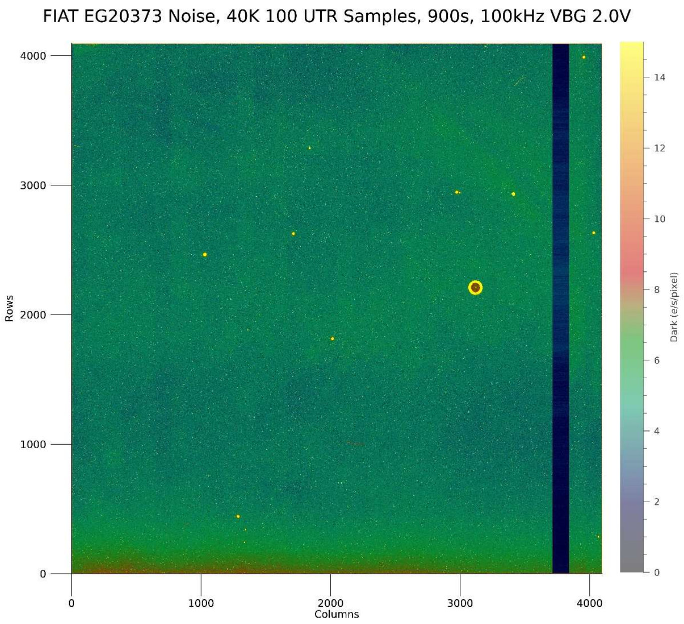
Dark histogram



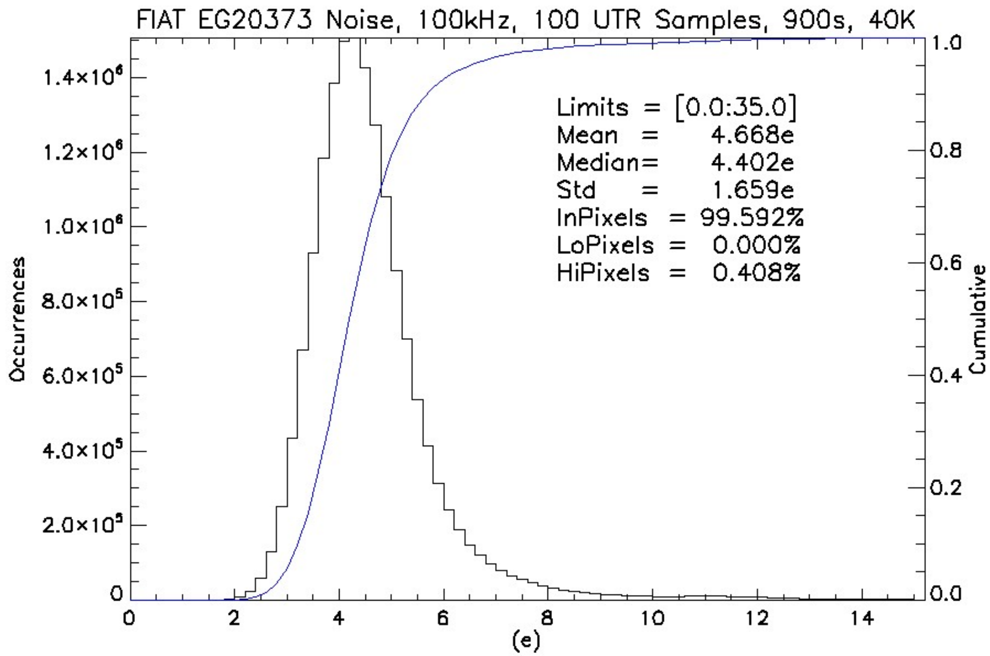


H4RG (EG) Noise Performance

Total noise from 900s at 40K, 100 UTR samples, Std. dev. of 20 DITs



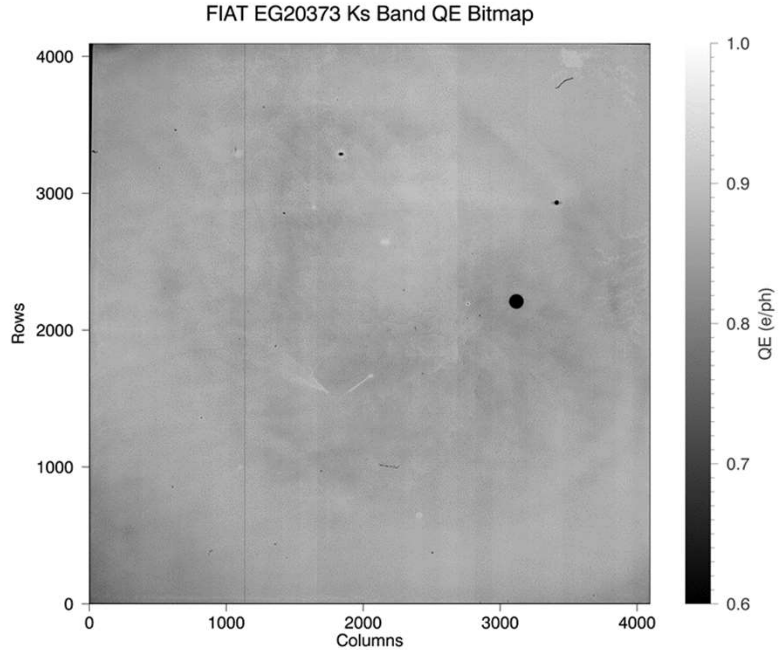
Noise histogram



H4RG (EG) QE Performance

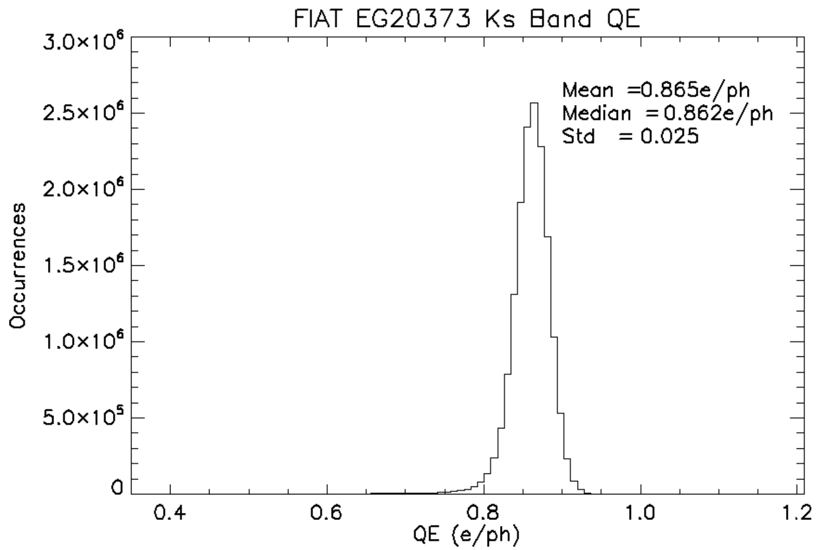
QE Ks band – corrected for illumination gradient

- Uncertainty ~5.2%



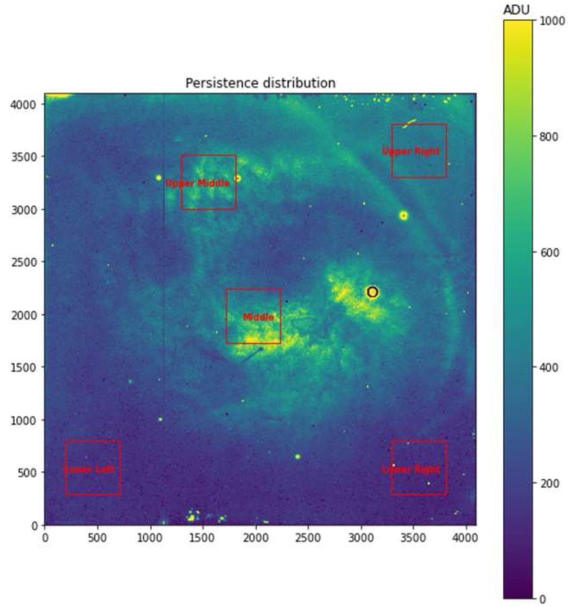
Ks band QE histogram

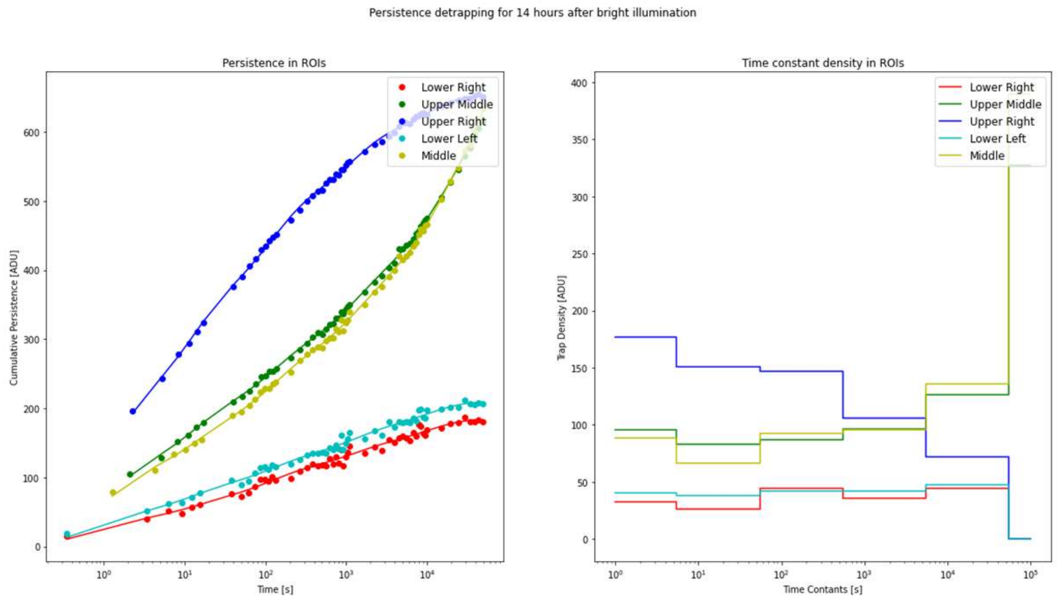
- Median QE 86.2%
- Non-uniformity ~2.9%



Persistence Characterisation

- Persistence evaluated at different temperatures from 40K to 90K
  - An algorithm implements persistence correction, based on the history of detector illumination, trap density and their time constants





[Tulloch, S. et al., Predictive model of persistence in H2RG detectors, J. of Astronomical Telescopes, Instruments, and Systems, 5(3), 036004 (2019)]

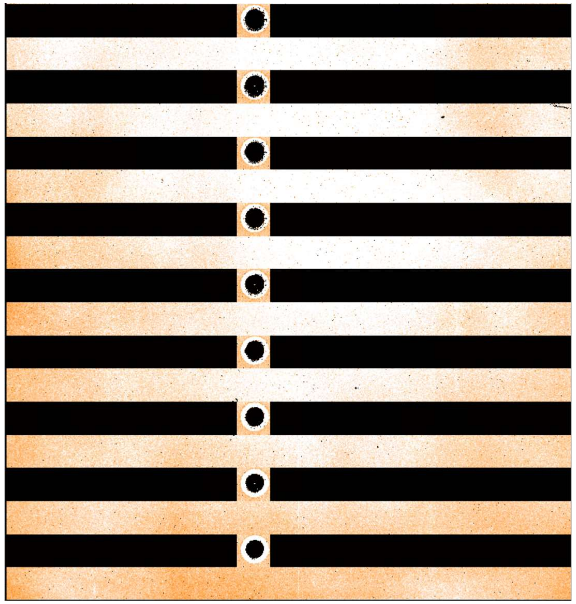
Special Readout Modes

Window resets – mitigate persistence from bright objects

- 9 window regions to reset bright objects

Interleaved window and science readout – for AO corrections of M4

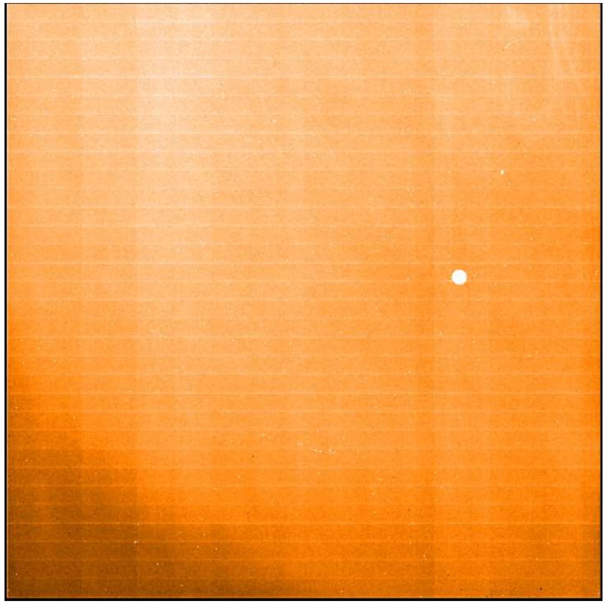
- A small window region is read out interleaved with full frame readout



Special Read Modes

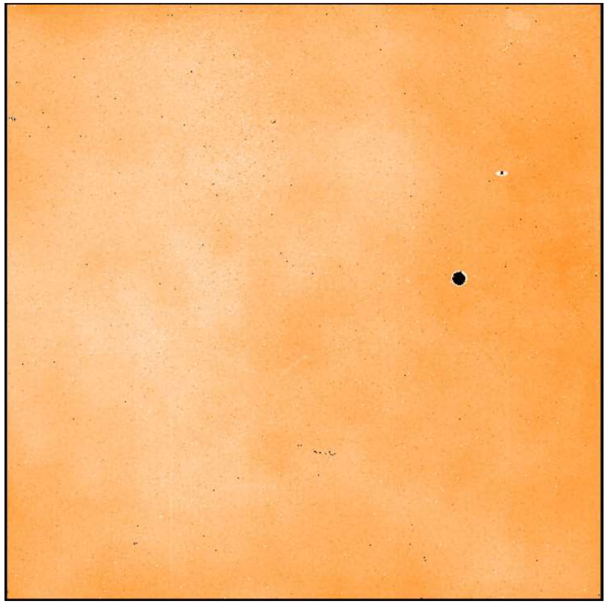
Artifacts of interleaved window and science read mode

- Horizontal structure seen every time the window region is accessed



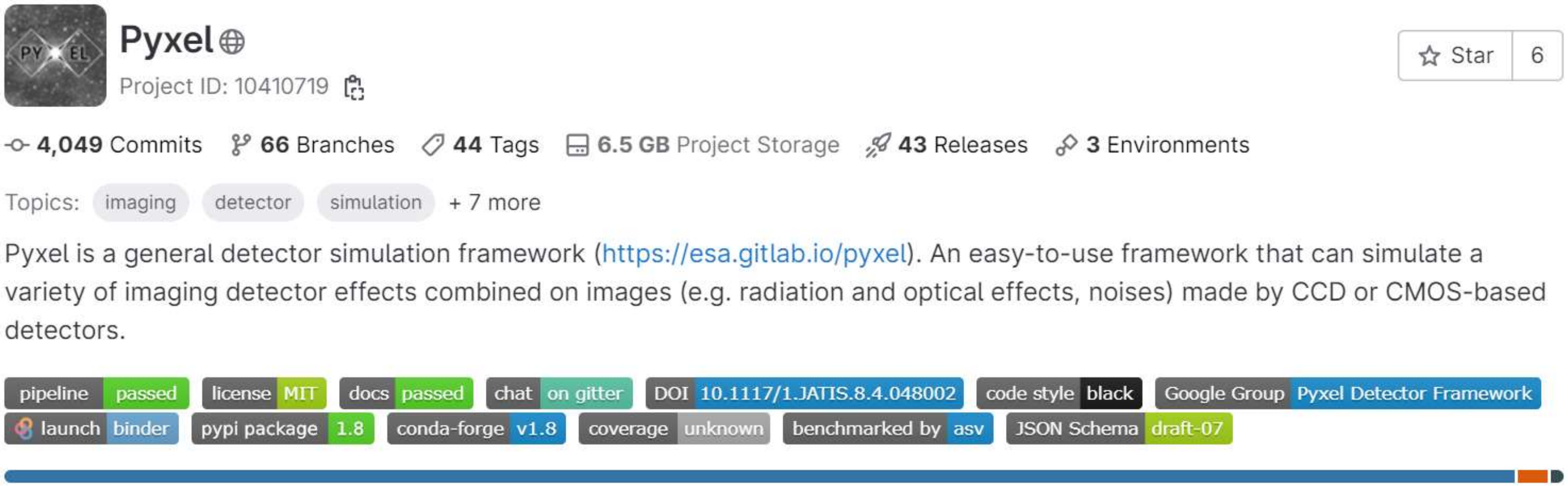
Artifacts of interleaved readout mode cancels out

- Structure cancels out in a CDS or UTR frames



PyXel Simulator

- Developed in collaboration with ESA, version 1.9 is released
- More info on PyXel:
  - PyXel paper: https://doi.org/10.1117/12.2314047
  - Sphynx documentation: https://esa.gitlab.io/pyxel/doc
  - Gitlab repo: https://gitlab.com/esa/pyxel

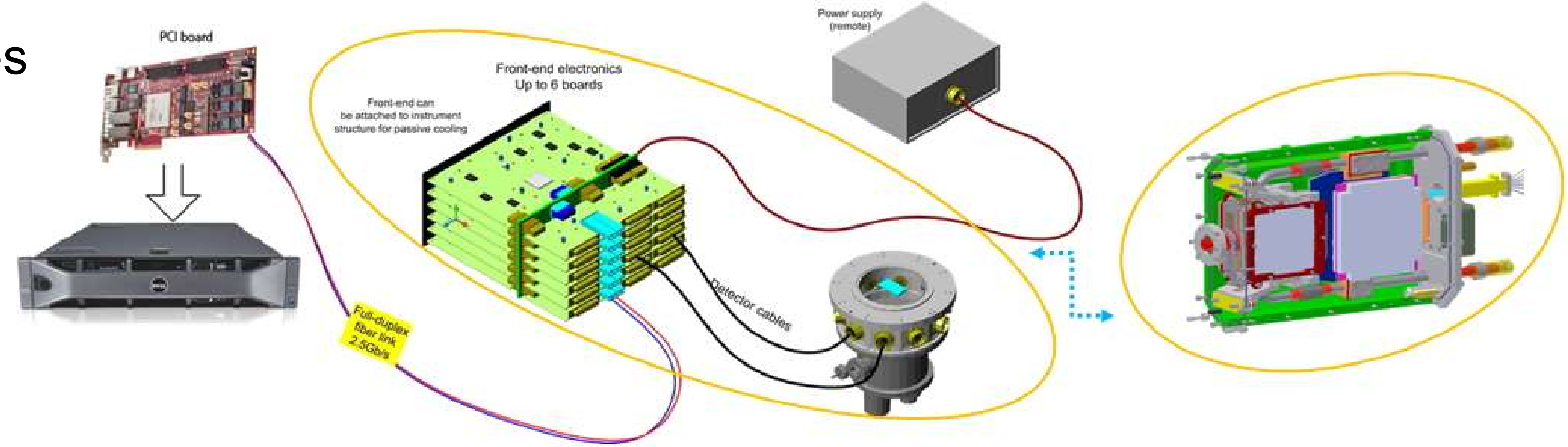


ESO detector controller NGCII

ESO standard detector controllers

ESO has a long history of developing and maintaining its own controllers

- Already in 1986 ESO has developed and was operating its own controller
- Between 1998 to 2008 ESO had two different controllers in operation at its observatories: one for infrared (IRACE) and one for optical applications (FIERA), both with great success
- From these controllers we have developed the new common controller, called **NGC**. Since 2012 ESO has been using NGC systems to operate its detector systems at the ESO Paranal observatories



NGCII, the successor of NGC

- After almost 10 years in operation, due to obsolescence and new ELT requirements:
- We have decided to go for a new controller development (NGCII)
- NGCII will remain as a general detector controller and will become ESO's standard controller for all ELT and new VLT instruments
- Ability to readout any type of detectors (as known today for our projects)
- In order to reduce the development effort and time we decided to adopt the **MicroTCA.4** standard as the baseline infrastructure for the NGCII system

MTCA

xTCA

Telecommunication and Computing Architecture
MTCA (Micro TCA) derived from TCA, ATCA designed for smaller application. Maintained by PICMG. Interconnect is PCIe based.

There are different flavors of the standard
MicroTCA.1
MicroTCA.2
MicroTCA.3
MicroTCA.4
MicroTCA.4.1

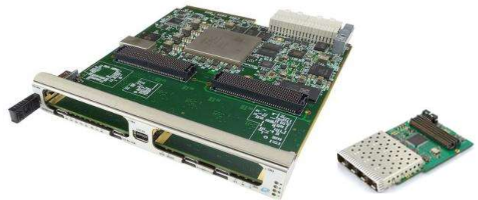
PICMG®

MTCA

- Rack ✓
- Backplane ✓
- FPGA Module ✓
- 10 GbE ✓
- Power Supply ✓
- System Controller ✓
- Debug Tools ✓
- ADC Module ✗
- Clock/Bias Module ✗
  (Management controller available)

600W Mains Interface

PCIe Switch (MCH)



Zynq Ultrascale+ FPGA Module with SPF+ Slots

Debug Interposer

MMC Controller

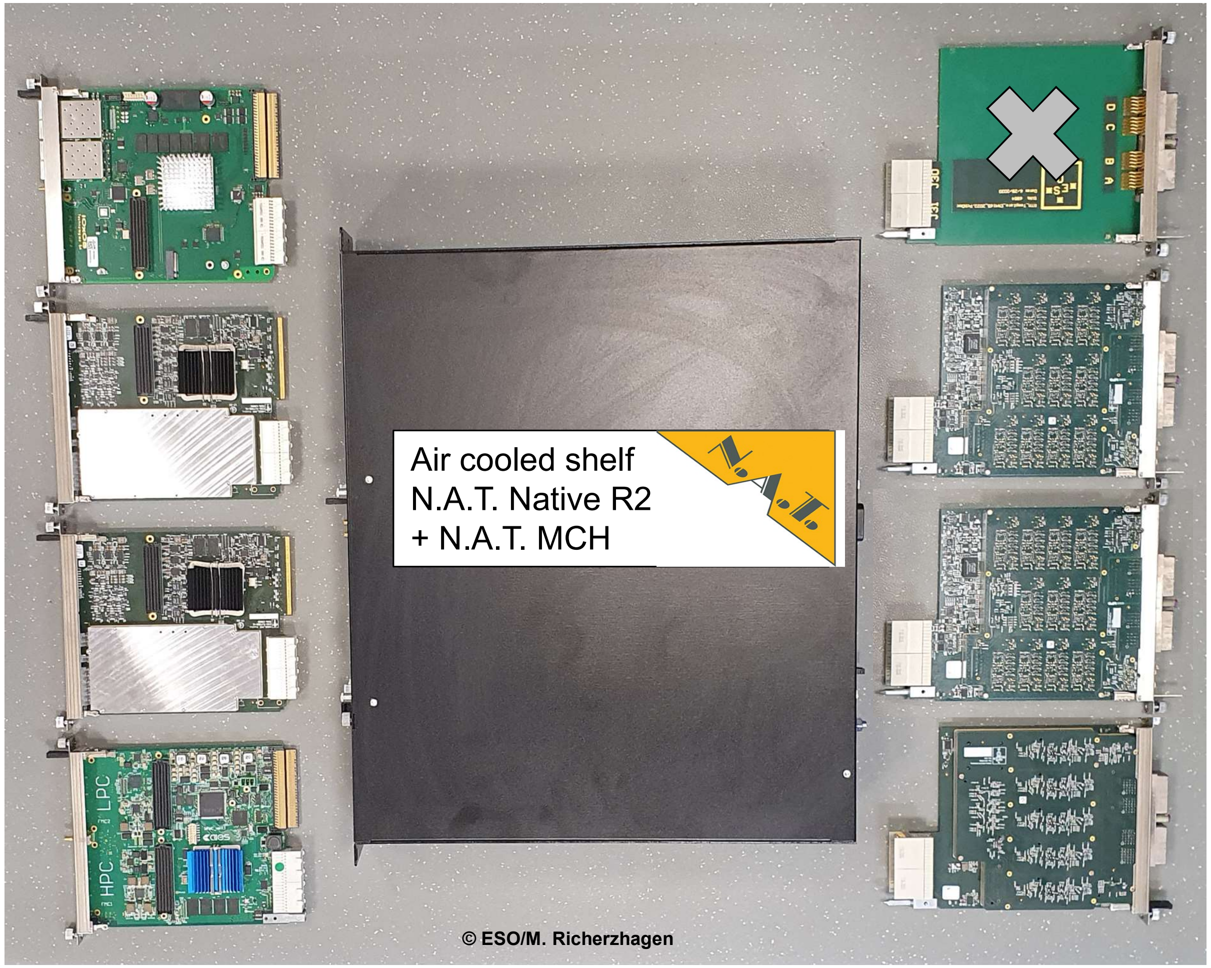
5 Slot Compact Shelf

NGCII for CMOS (IR) type detectors

IOXOS IFC1414
New Board for ESO
Zynq US+ FPGA

2x AQ22 AMC
ADC Module
Artix FPGA
In-house Dev.

AIES MFMC
Artix FPGA



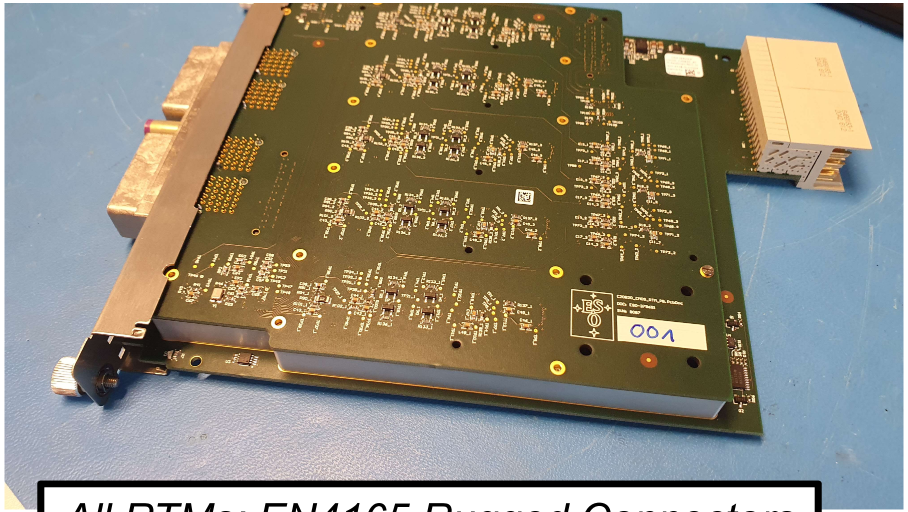
APD Bias RTM
Negative APD Bias
In development
Not needed for first light

2x CMOS AQ22 RTM
Signal Conditioning
In-house Development

CMOS C20B20 RTM
Clock + DC Bias
In-house Development

MTCA.4 Modules (In House)

- CMOS Clock/Bias RTM
  - 20 CMOS Bias Channels
    - <2μV/K Drift
    - 0..5V
  - 20 CMOS Clock Channels
    - 2.0V to 5V CMOS Clock into 5m cable
- CCD Clock RTM
  - 24 CCD Clock Channels
    - Tri-Level ±13.2V
    - Optional Slope Control
- CCD Bias RTM
  - 24 CCD Bias Channels
    - 0V…34V, low drift
    - ±17V, low drift

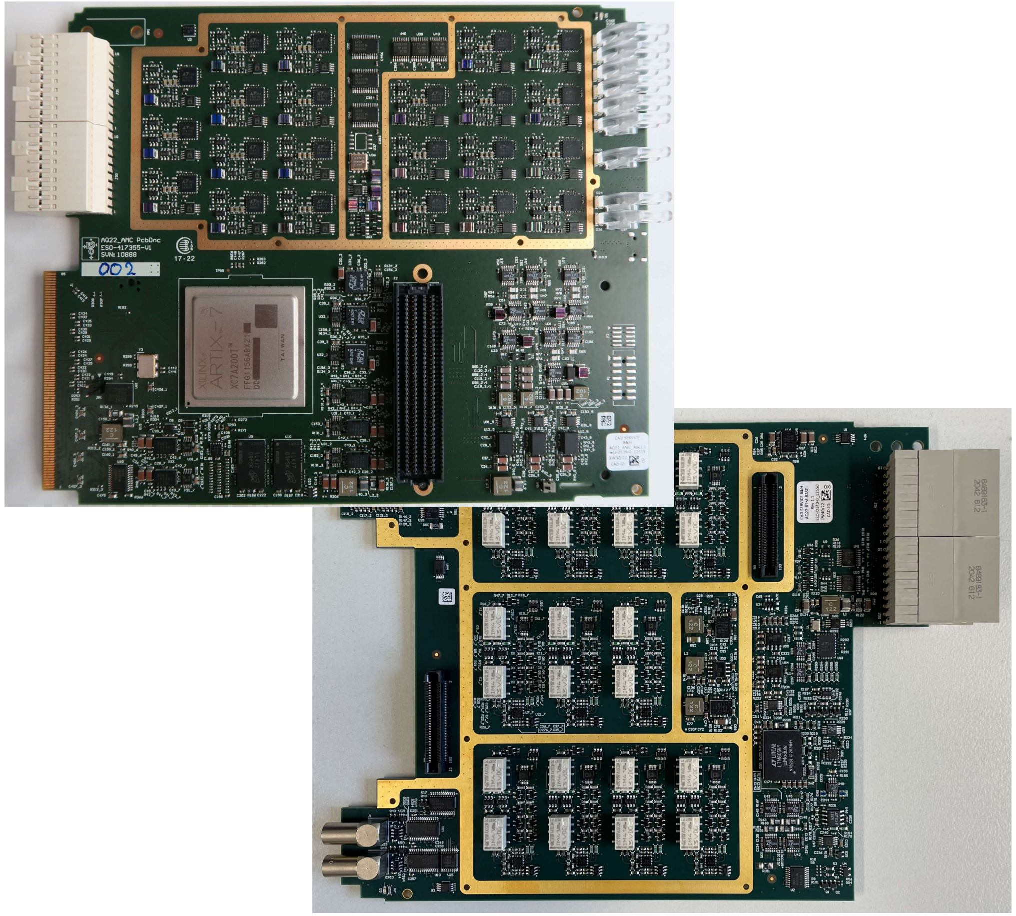


All RTMs: EN4165 Rugged Connectors

Image: TE Connectivity

MTCA.4 Modules (In House)

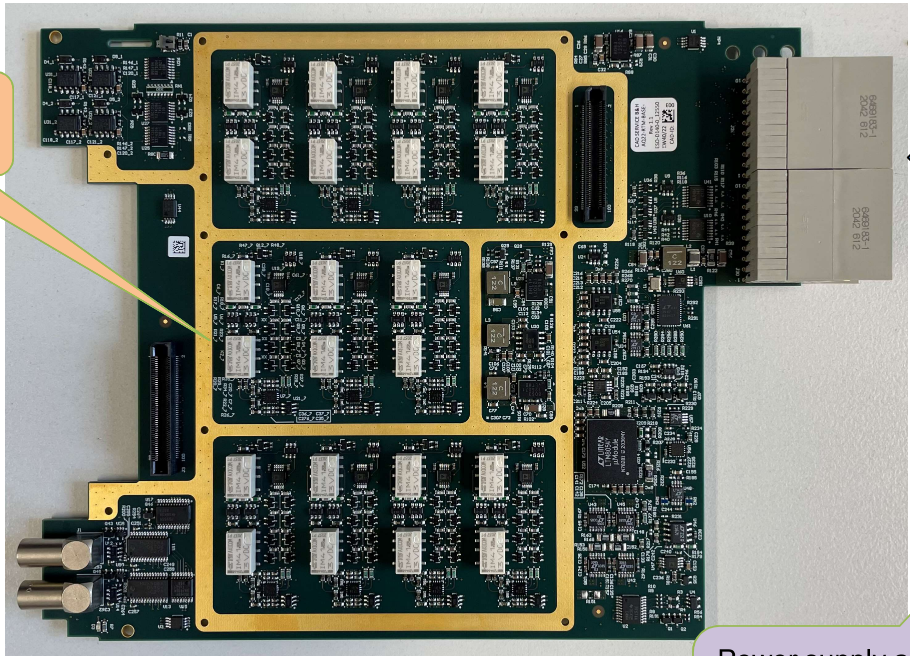
- 22 Channel ADC AMC
  - 22 ADC Channels
  - SAR ADCs
  - 15Msps
  - 16 bit / 18 bit
  - Custom Sequencing and Triggering

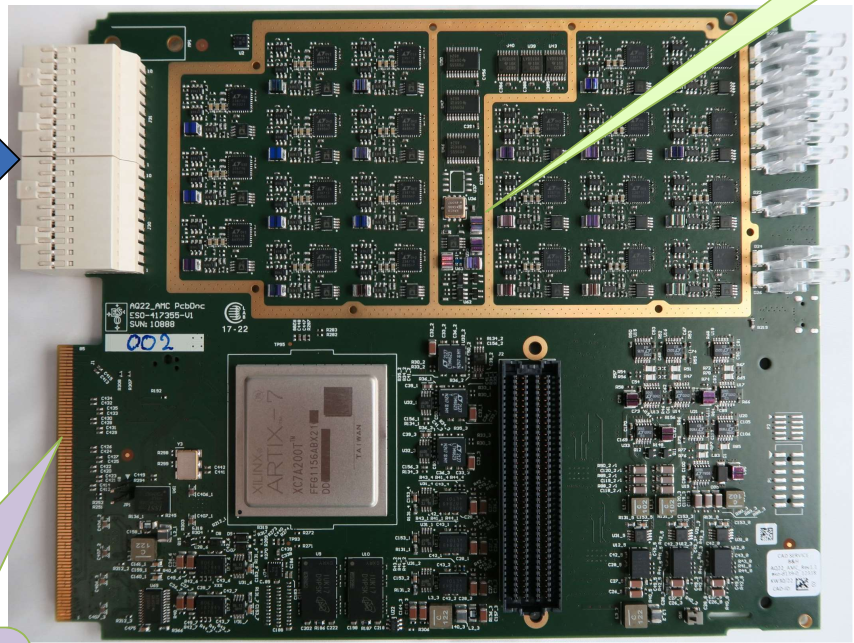


- 22 Channel Analog RTM
  - All Detector (CCD/CMOS) specific circuits on RTM

NGCII Prototyping

- AQ22 AMC/RTM, 22 channel video module for CMOS (IR) type detectors





NGCII standard enclosure

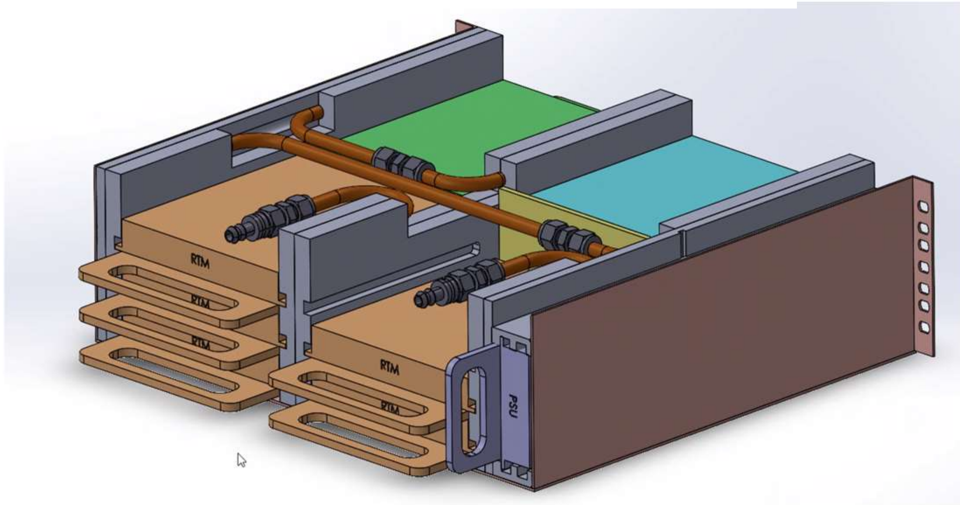
- ❑ NGCII standard housing is air cooled:

  NAT NATIVE-R2

- ➢ Integrated power supply, 230V AC interface
- ➢ The fan speed is controlled via the shelf
- ➢ Dimensions:

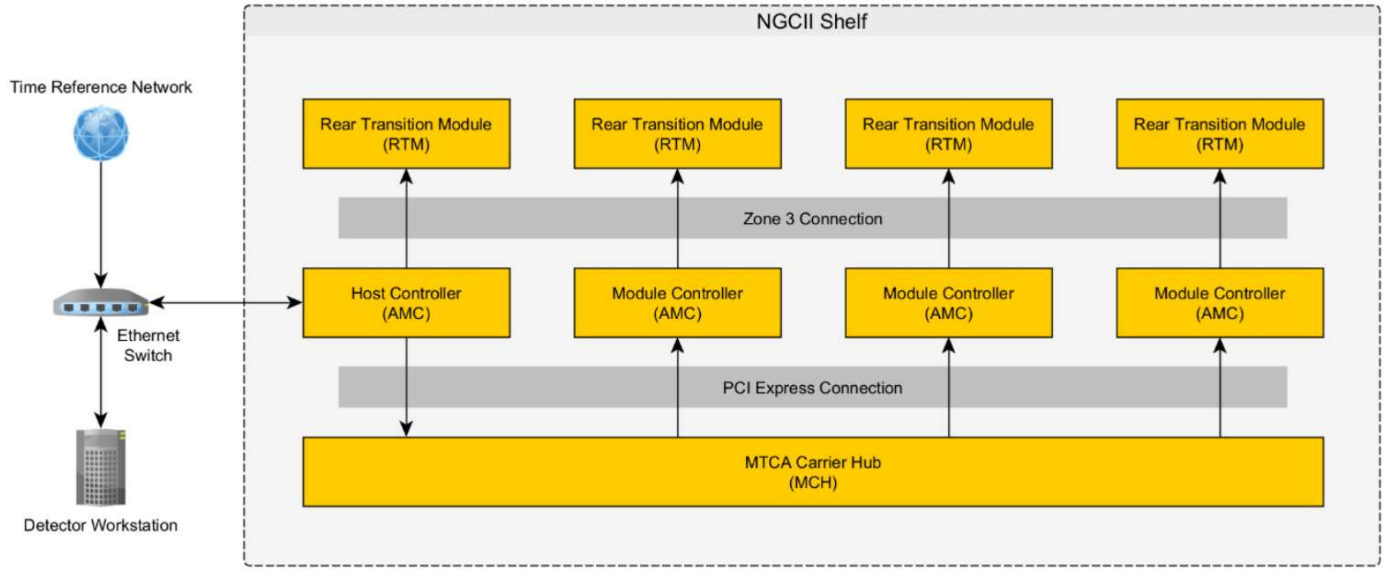
  W: 19”, H: 2HU, D: 400 mm

- ❑ NGCII has to offer a standalone version of its enclosure, so a fan less version is required
- ➢ ANU, Australian National University, is developing a water cooled fanless enclosure for NGCII



Firmware

- ❑ All intelligence in AMCs
- ➢ Host controller based on Zynq US+ module
  - PCIe Root Complex
  - 10GbE + 1GbE Interface
- ➢ Module controller on other AMCs
  - Clock Sequencer
  - Data Acquisition

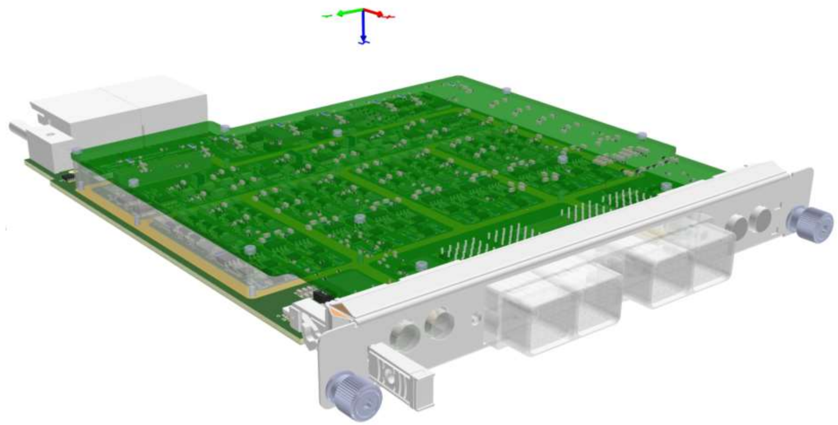


NGCII systems for ELT and 4th gen VLT instruments

Instrument	Detector System	Number of NGCII systems
METIS (ELT)	SAPHIRA, Hawaii-2RG, GEOSNAP	7x
MICADO (ELT)	Hawaii-4RG	9x
HARMONI (ELT)	CCD231-84, Hawaii-4RG	12x
PDS (ELT)	Hawaii-2RG	1x
FORS upgrade (VLT)	CCD231-84	2x
MAVIS (VLT)	CCD290-99, SAPHIRA	6x
CUBE (VLT)	CCD290-99	2x
ANDES (ELT)	CCD290-99, Hawaii-4RG	9x
MOSAIC (ELT)	CCD231-84, Hawaii-4RG	5x

Perspective

- First light with SAPHIRA detector achieved
- Work on first light with HAWAII-2RG
- Work on modules for first light of CCD detector:
  - CCD C24 RTM (24x variable clock)
  - CCD B24 RTM (24x 15V/30V bias)
  - CCD AQ8 RTM (8x CCD specific AQ channel)
- Revision 2 of modules
- Mass production begin of next year



NGCII first light
SAPHIRA Infrared detector