ESA's NewAthena X-Ray Telescope and its Wide Field Imager

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MAX PLANCK INSTITUTE
FOR EXTRATERRESTRIAL PHYSICS

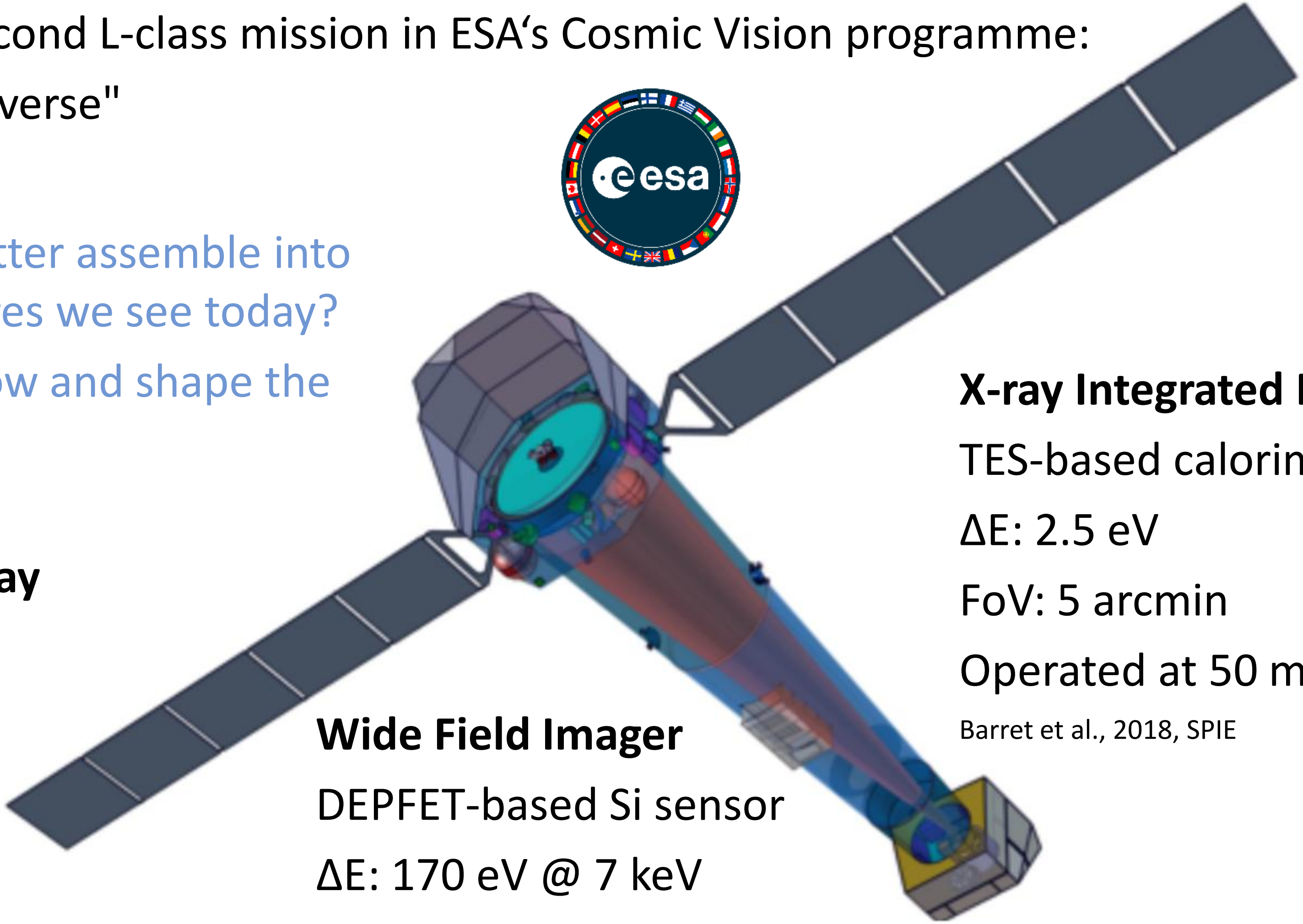
Advanced **T**elescope for **H**igh **En**ergy **A**strophysics

Athena: 2014 - 2022

In 2013 excepted as second L-class mission in ESA‘s Cosmic Vision programme:
"Hot and Energetic Universe"

How does ordinary matter assemble into the large-scale structures we see today?

How do black holes grow and shape the universe?



Movable mirror array

Focal length: 12 m

Silicon Pore Optics

1.4 m² @ 1 keV

5 arcsec HEW

Wide Field Imager

DEPFET-based Si sensor

ΔE: 170 eV @ 7 keV

FoV: 40 arcmin

High countrate capability

Launch:

~ 2028

Ariane 64

L2 orbit

X-ray Integrated Field Unit

TES-based calorimeter

ΔE: 2.5 eV

FoV: 5 arcmin

Operated at 50 mK

Barret et al., 2018, SPIE

~7100 kg

~10 kW

>= 5 year mission

Material from ESA

NewAthena: 2023 -

Re-established as an L-class mission in 2023 (launch after LISA) with mission adoption planned in 2027

How does ordinary matter assemble into the large-scale structures we see today?

How do black holes grow and shape the universe?

Launch:

~ 2037

Ariane 64

L1 orbit

Movable mirror array

Focal length: 12 m

Silicon Pore Optics

$1.0\ m^2$ @ 1 keV

9 arcsec HEW

Wide Field Imager

DEPFET-based Si sensor

ΔE: 160 eV @ 7 keV

FoV: 40 arcmin

High countrate capability

X-ray Integrated Field Unit

TES-based calorimeter

ΔE: 4 eV

FoV: 5 arcmin

Operated at 100 mK

Barret et al., 2018, SPIE

~7100 kg

~10 kW

>= 5 year mission

Material from ESA

Population of Accreting Supermassive Black Holes

Credit: J. Aird (UoE), F. Carrera (IFCA)

Fundamental science question

How common were active galaxies when the Universe was ~0.5-1 Billion years* young and when most black holes were rapidly growing.

*: current age of the Universe:13.8 Billion years

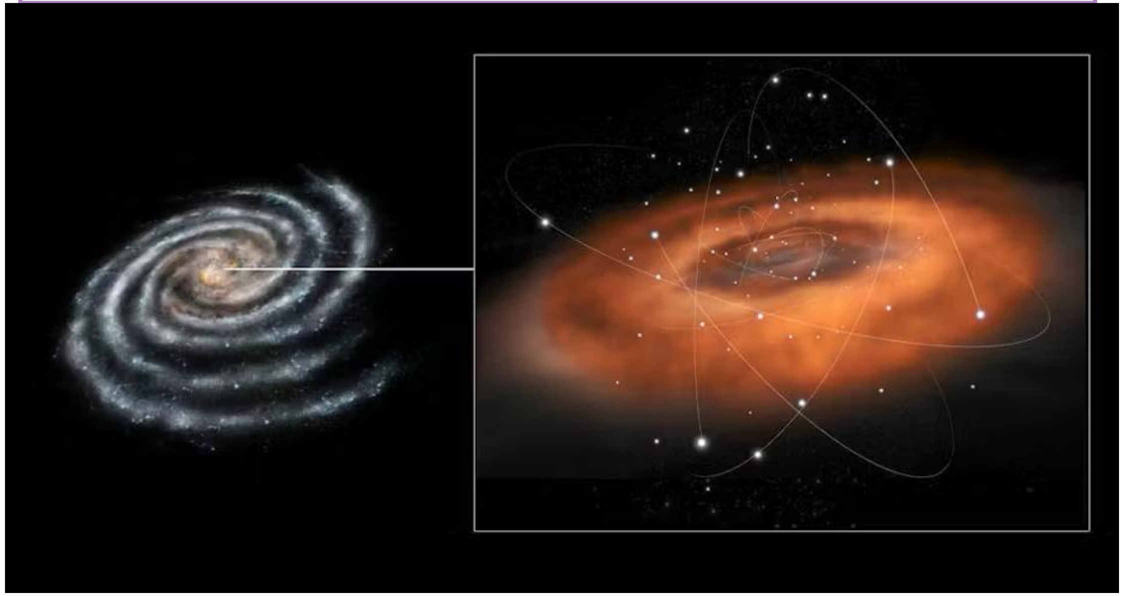
Experiments

Find and characterise typical active galaxies at redshift z~8

Key mission and WFI performance

Angular resolution, grasp and WFI Non X-Ray Background (NXB)

Black hole in the center of a galaxy



Observation:

- Large (~200 pointings, ~1.4 years) WFI LDA Survey covering ~90deg^2

Slide prepared by A. Rau

Energy Released by Active Galaxies affect their Surroundings

Credit: F. Carrera (IFCA), A. Georgakakis (NOA), L. Zappacosta (OAR)

Fundamental science question

How does the energy released by the supermassive black hole affect the evolution of the galaxy?

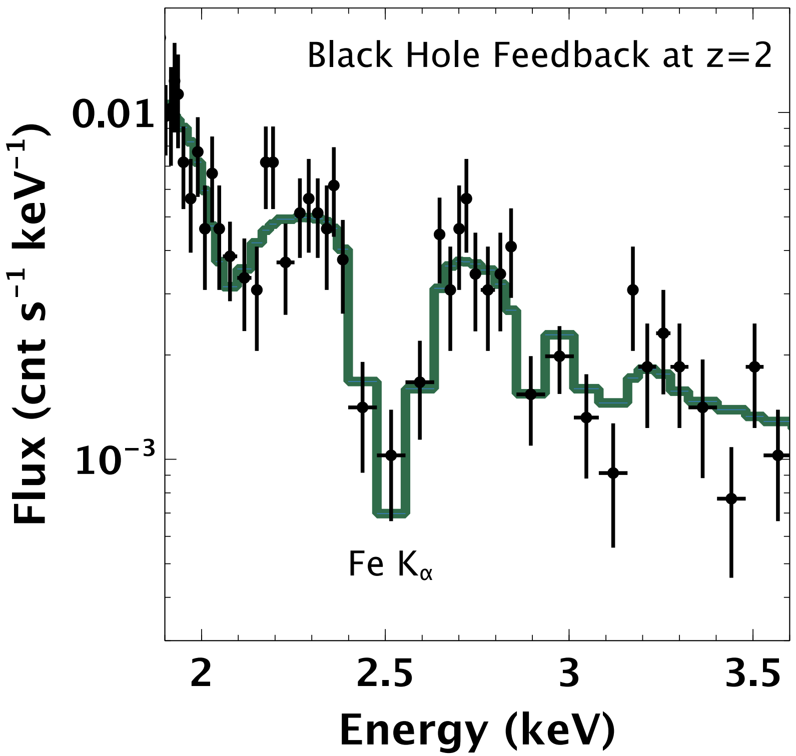
Experiments

Measure the incidence and energetics of outflows up to cosmic noon ($z \leq 4$)*

*z=4: Universe was 1.5 Billion years old

Key mission and WFI performance

Angular resolution, grasp, WFI Non X-Ray Background (NXB), energy resolution



Observation:

- The large survey mentioned before

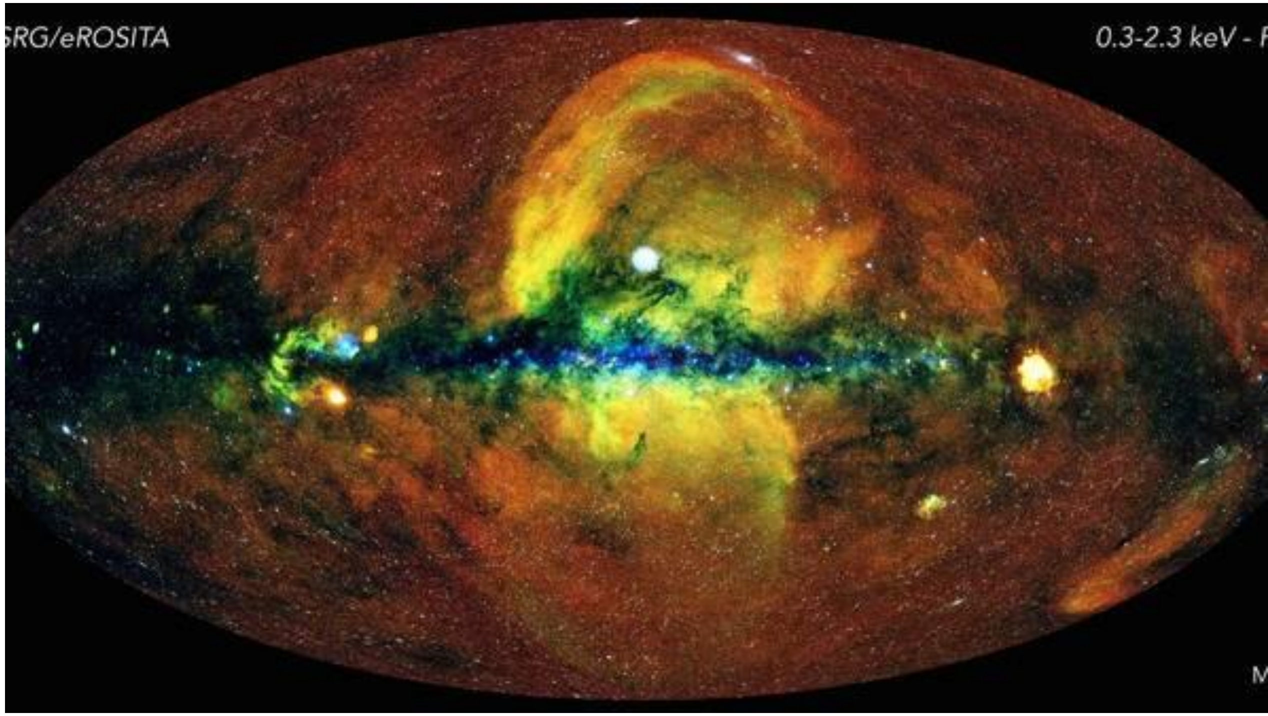
Slide prepared by A. Rau

Galactic “bubbles” caused by Active Galaxies

Credit: A. Simionescu (SRON), N. Truong (GSFC)

Fundamental science question

How is the energy from active galaxies released in the hot galaxy atmosphere?



Experiments

Detect "eROSITA bubbles"* surrounding individual galaxies

Key mission and WFI performance

Angular resolution, WFI area, grasp, FoV

Observation:

- WFI LDA observations of ~10 individual galaxies (~1day per galaxy)

Slide prepared by A. Rau

Galactic "bubbles" caused by Active Galaxies

Fundamental science question

How is the energy from active galaxies released in the hot galaxy atmosphere?

Experiments

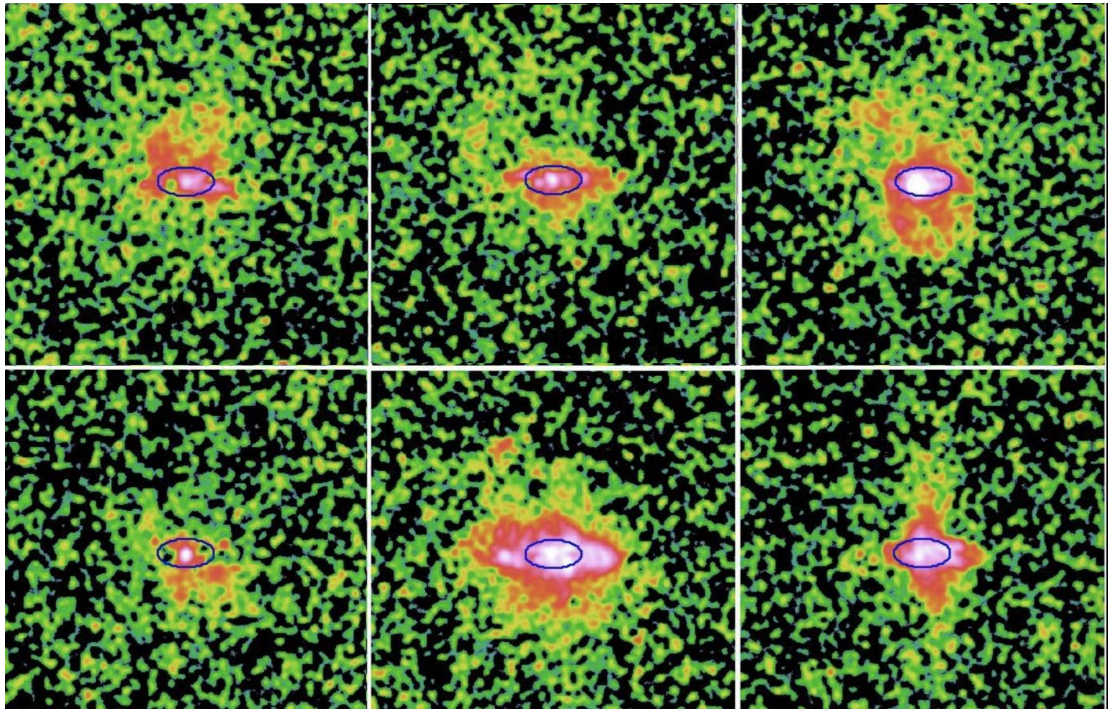
Detect "eROSITA bubbles"* surrounding individual galaxies

Key mission and WFI performance

Angular resolution, WFI area, grasp, FoV

Credit: A. Simionescu (SRON), N. Truong (GSFC)

WFI simulations of z=0.01 galaxies: bubbles are rare



Observation:

- WFI LDA observations of ~10 individual galaxies (~1day per galaxy)

Slide prepared by A. Rau

Map baryonic reservoirs: low-mass galaxy groups

Credit: F. Pacaud (Un. Bonn), figure adapted from Zhang et al., 2020, A&A, 2020, 642, 17

Fundamental science question

Chart where matter is stored in galaxy groups*, and study how it changes over time and connects to the larger cosmic structure.

*Galaxy Groups have ~10-50 member galaxies

Experiments

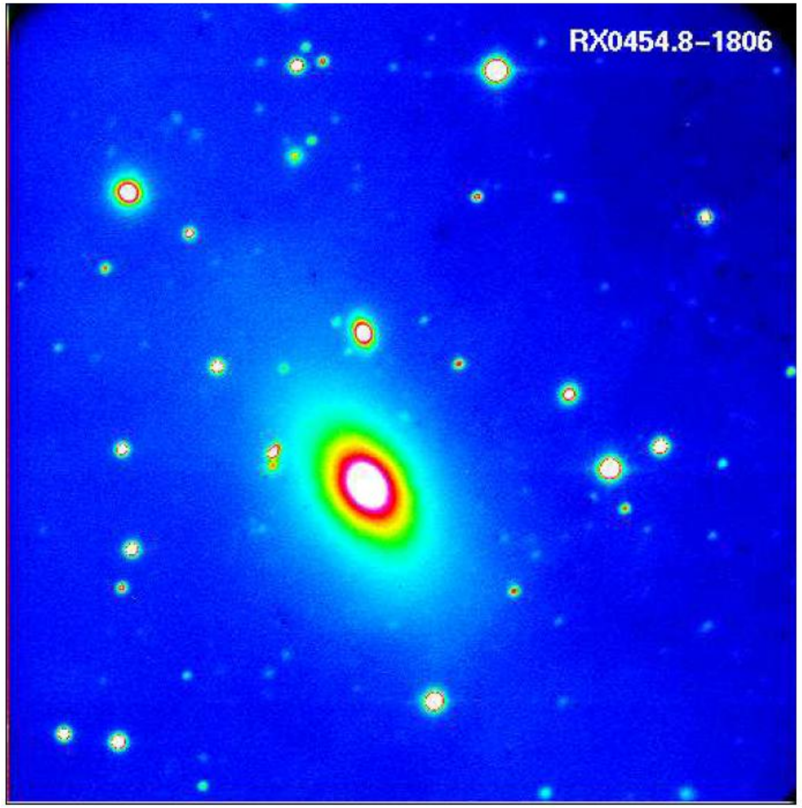
Determine the properties of the hot, i.e., X-ray bright, gas in galaxy groups at $z \geq 1$*

*z=1: Universe was 7.7 Billion years old

Key mission and WFI performance

Angular resolution, WFI area and energy resolution, grasp, X-ray stray light, spacecraft agility

A galaxy group



Observations:

- very large WFI LDA survey (~1000 pointings, ~4 months) covering ~400 deg^2

Slide prepared by A. Rau

Neutron Stars Equation-of-State (i.e., pressure-density relation)

Credit: S. Guillot (IRAP/Toulouse U.)

Fundamental science question

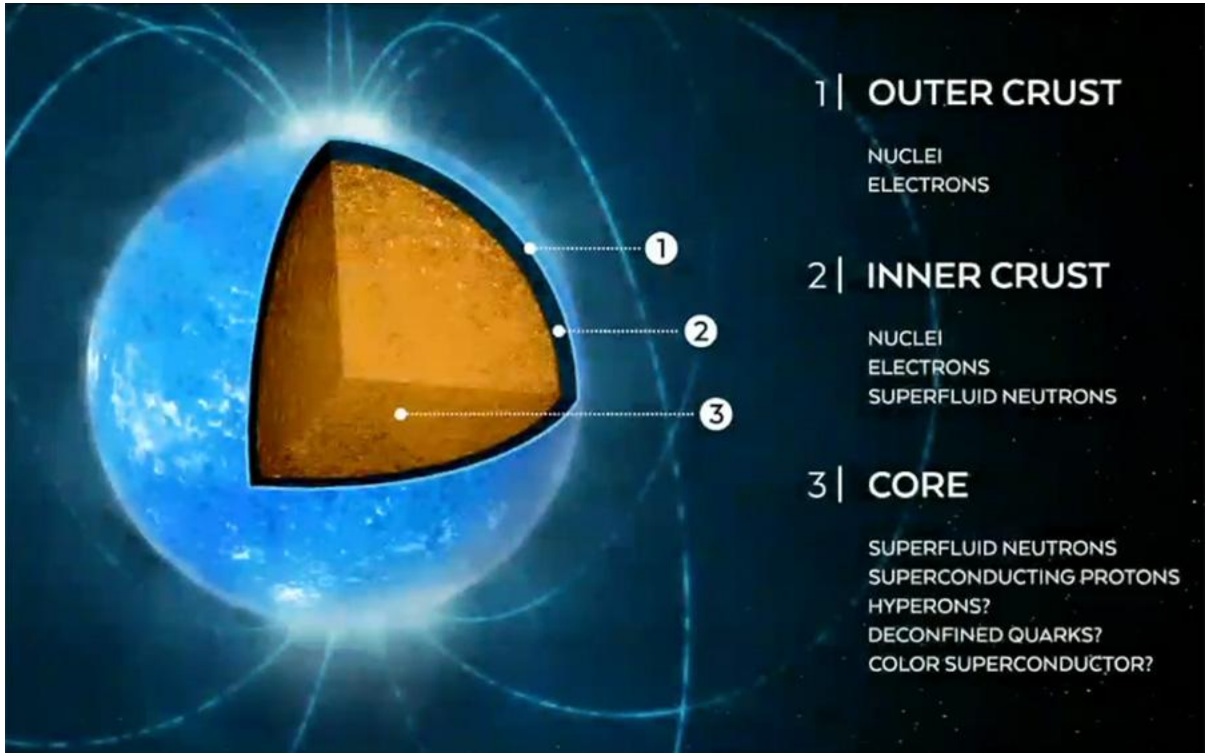
Constraining the Equation of State (EoS) of Neutron Stars (NSs)

Experiments

%-level radius in 2 rotationally-powered pulsars through pulse profile modelling

Key mission and WFI performance

WFI area, relative timing accuracy, area and NXB knowledge (calibration)



Observation:

- WFI FD in-focus for 2 sources

Slide prepared by A. Rau

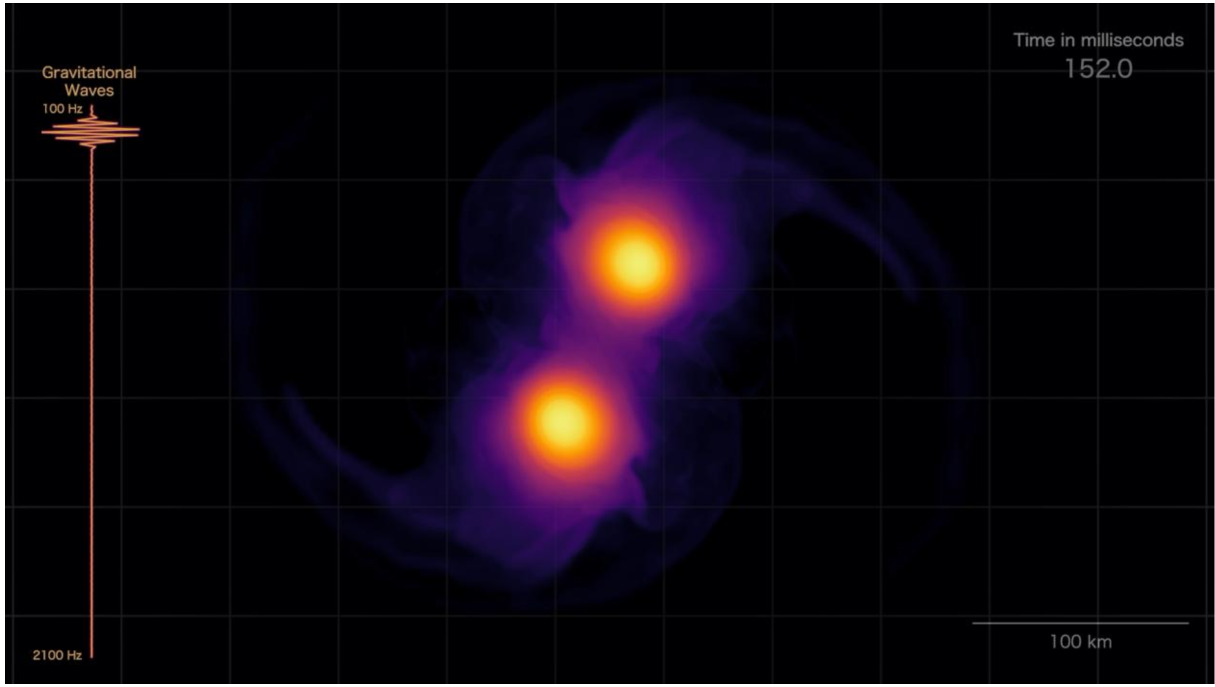
Multi-messenger astrophysics

Credit: Piro et al. (2022), NASA's Goddard Space Flight Center and STAG Research Centre/Peter Hammond

Fundamental science question

How does the X-ray emission of two merging Neutron Stars look?

Merging Neutron Star emit gravitational waves!



Experiments

Detect the X-ray counterparts of gravitational wave sources and monitor their brightness as function of time to constrain the nature of compact objects.

Key mission and WFI performance

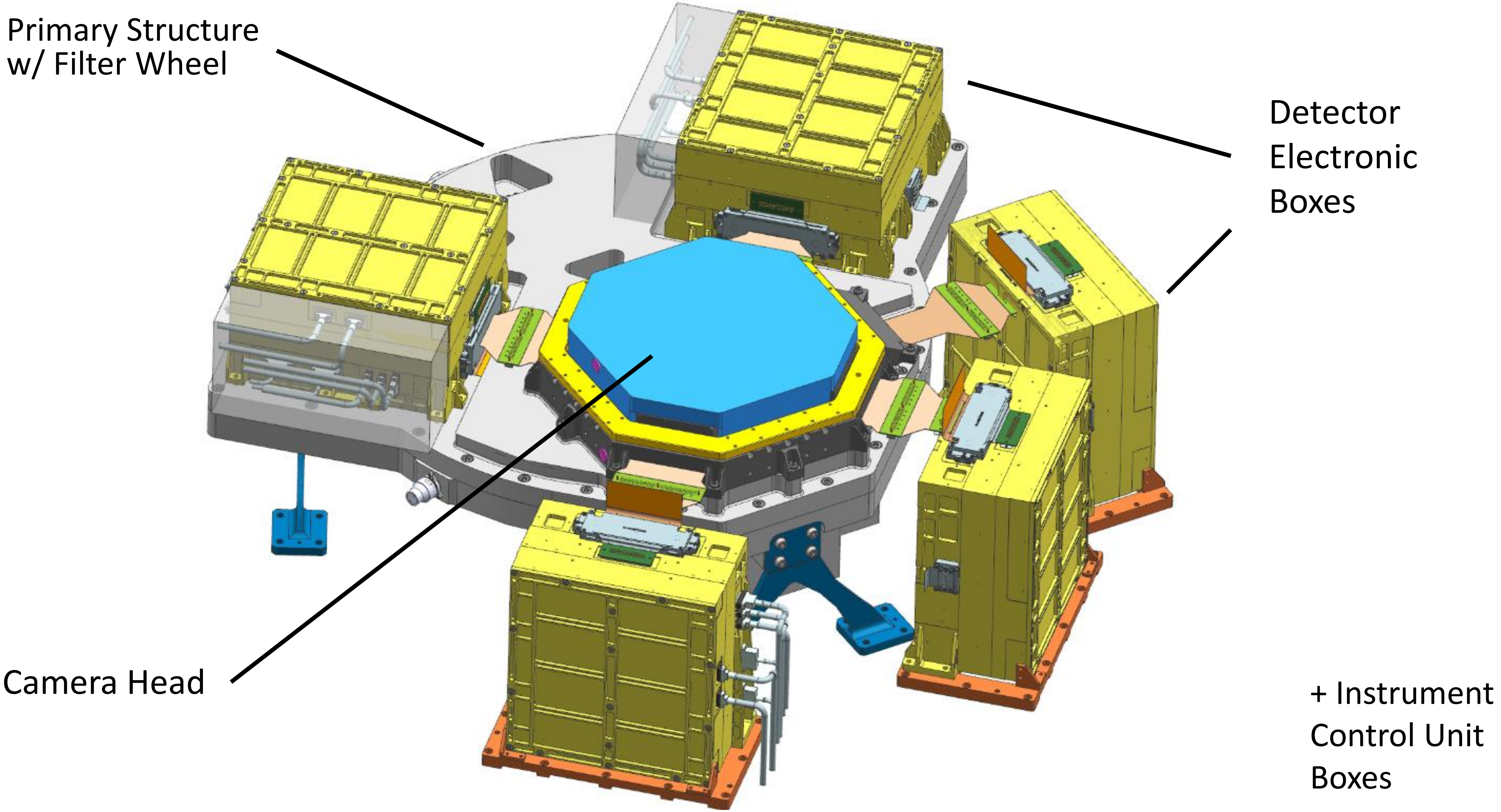
Field-of-regard, Target-of-Opportunity response, grasp

Observation:

- multiple WFI LDA pointings per source to map the relatively large grav. wave error boxes

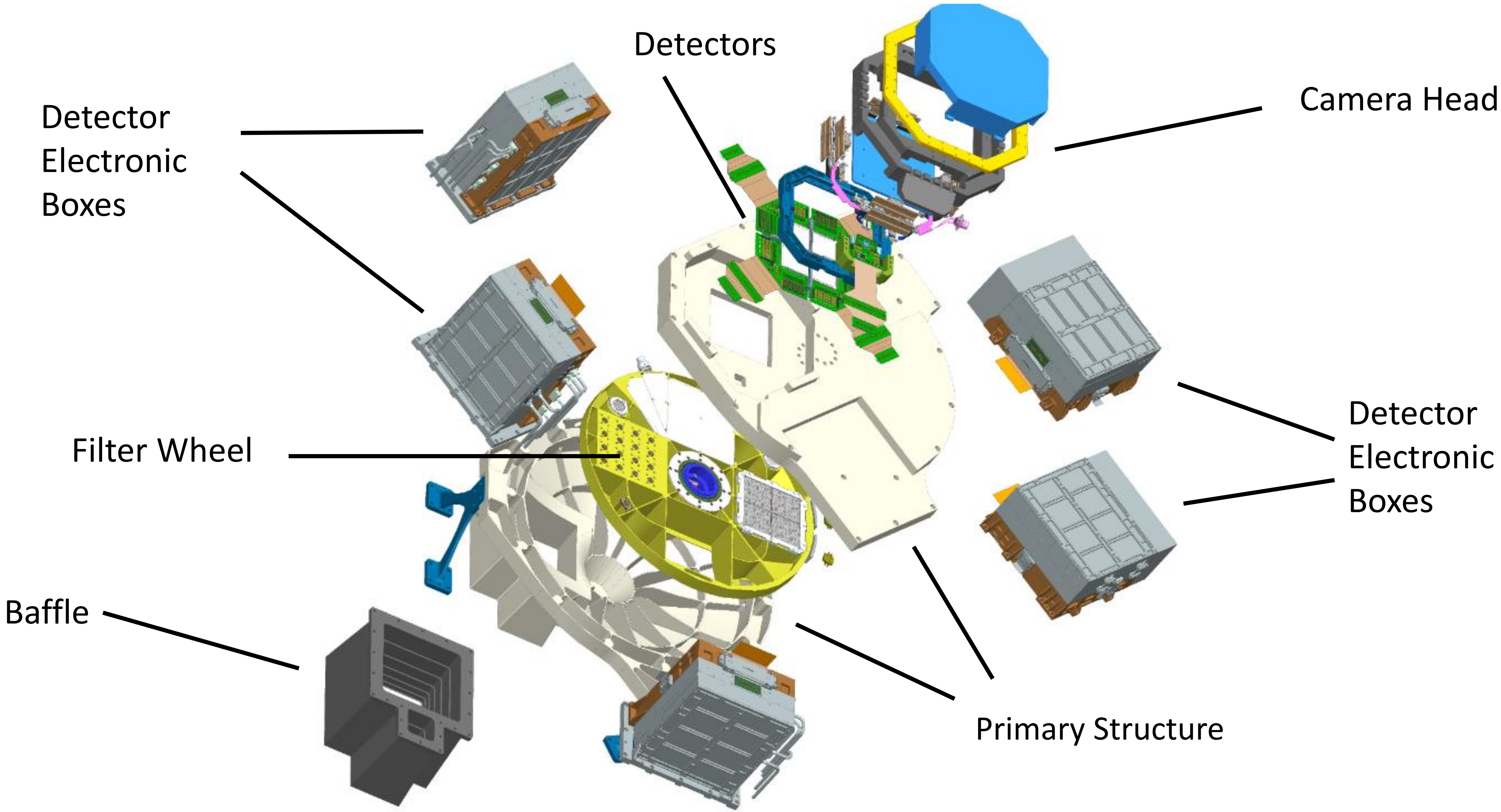
Slide prepared by A. Rau

WFI on Athena



CAD by R. Strecker

WFI on Athena



CAD by R. Strecker

Camera Head (WFI on Athena)

DEPFET pixels

130 µm x 130 µm each

Readout:

row-wise

column-parallel

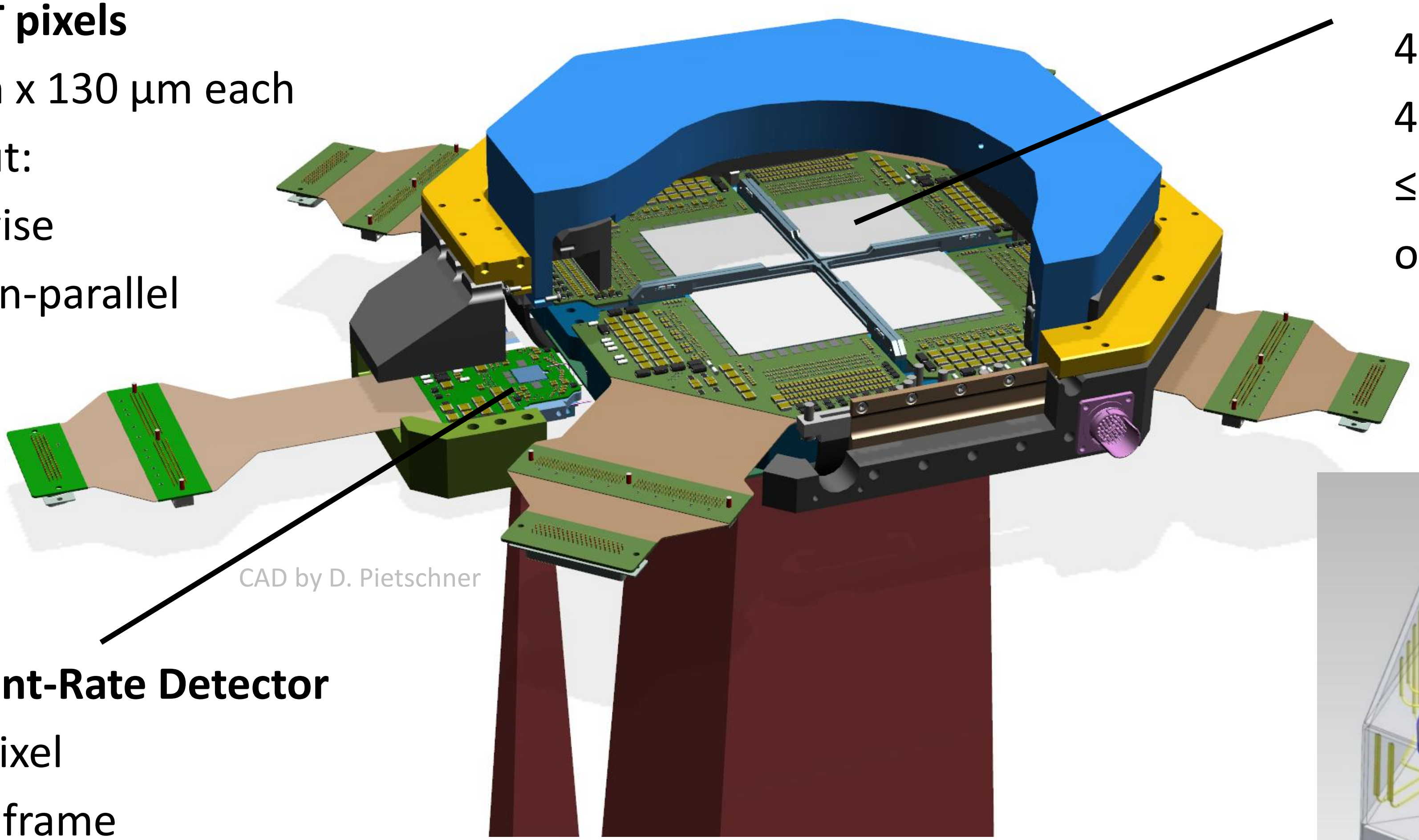
Large Detector Array

4 times 512 x 512 pixels

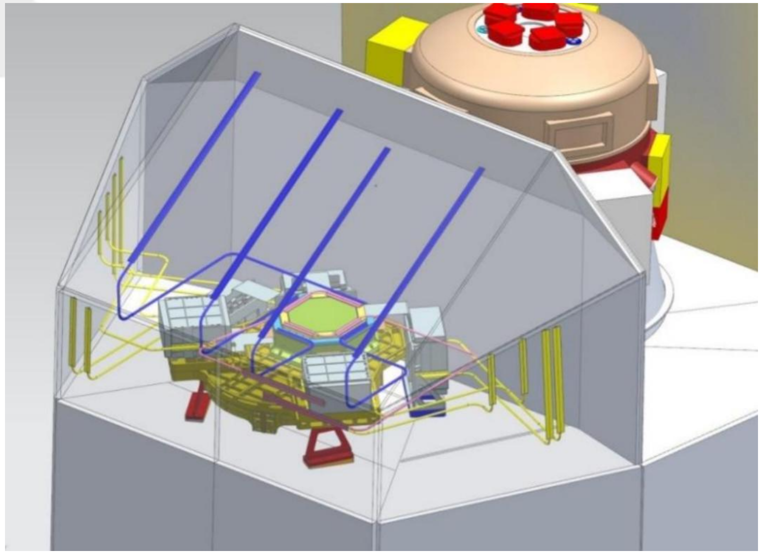
40 arcmin field of view in total

≤ 5 ms / frame

optional window modes



Thermal connections



High Count-Rate Detector

64 x 64 pixel

≤ 80 µs / frame

<1% pile-up, >80% throughput @ 1 Crab

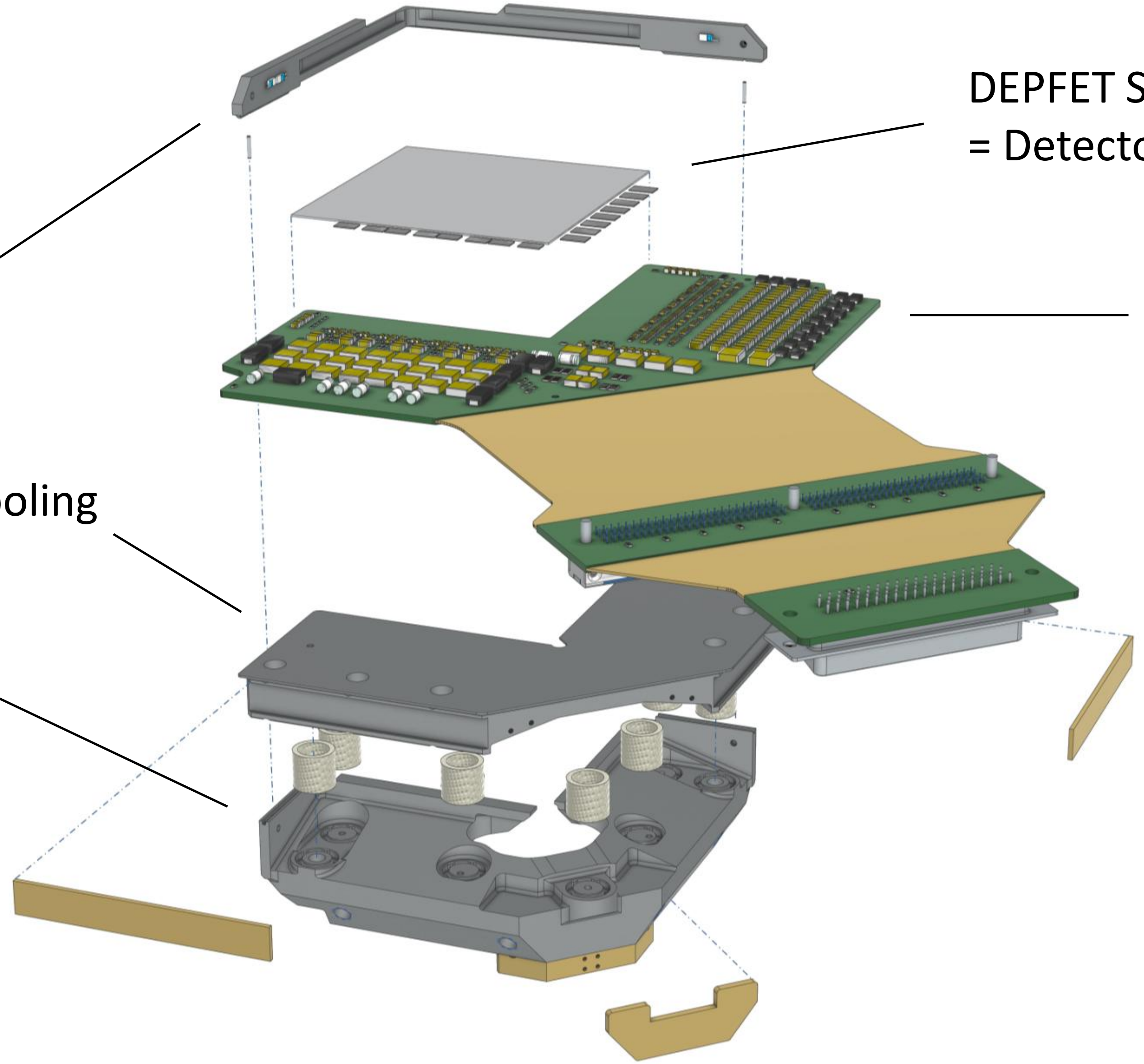
Even higher count rates achievable with filters

↓ Mirror

Material from ESA

DEPFET Detector (Large)

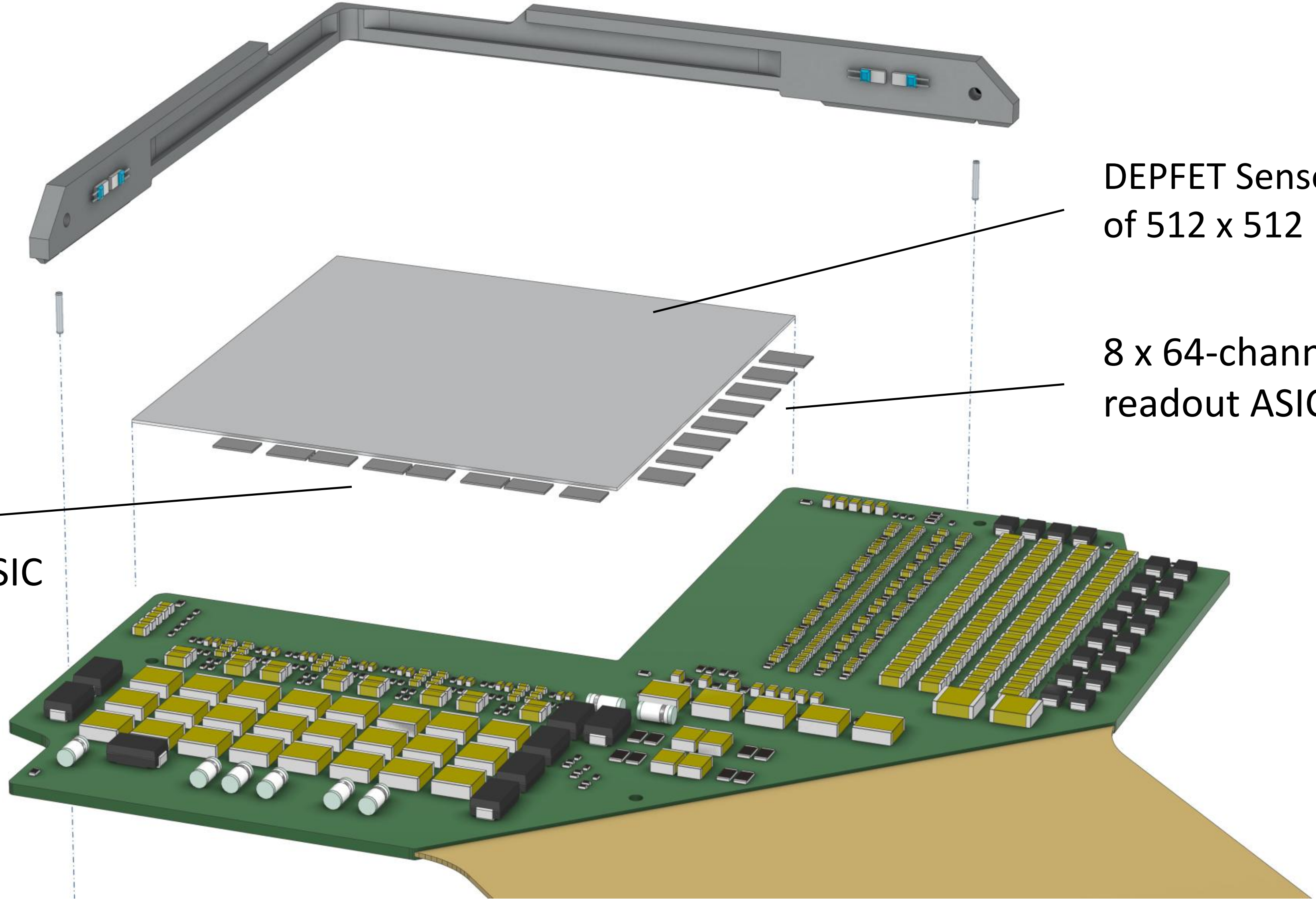
Large Detector:



CAD by D. Pietschner

DEPFET Detector (Large)

Large Detector:



DEPFET Sensor consisting of 512 x 512 DEPFET pixels

8 x 64-channel Veritas readout ASICs

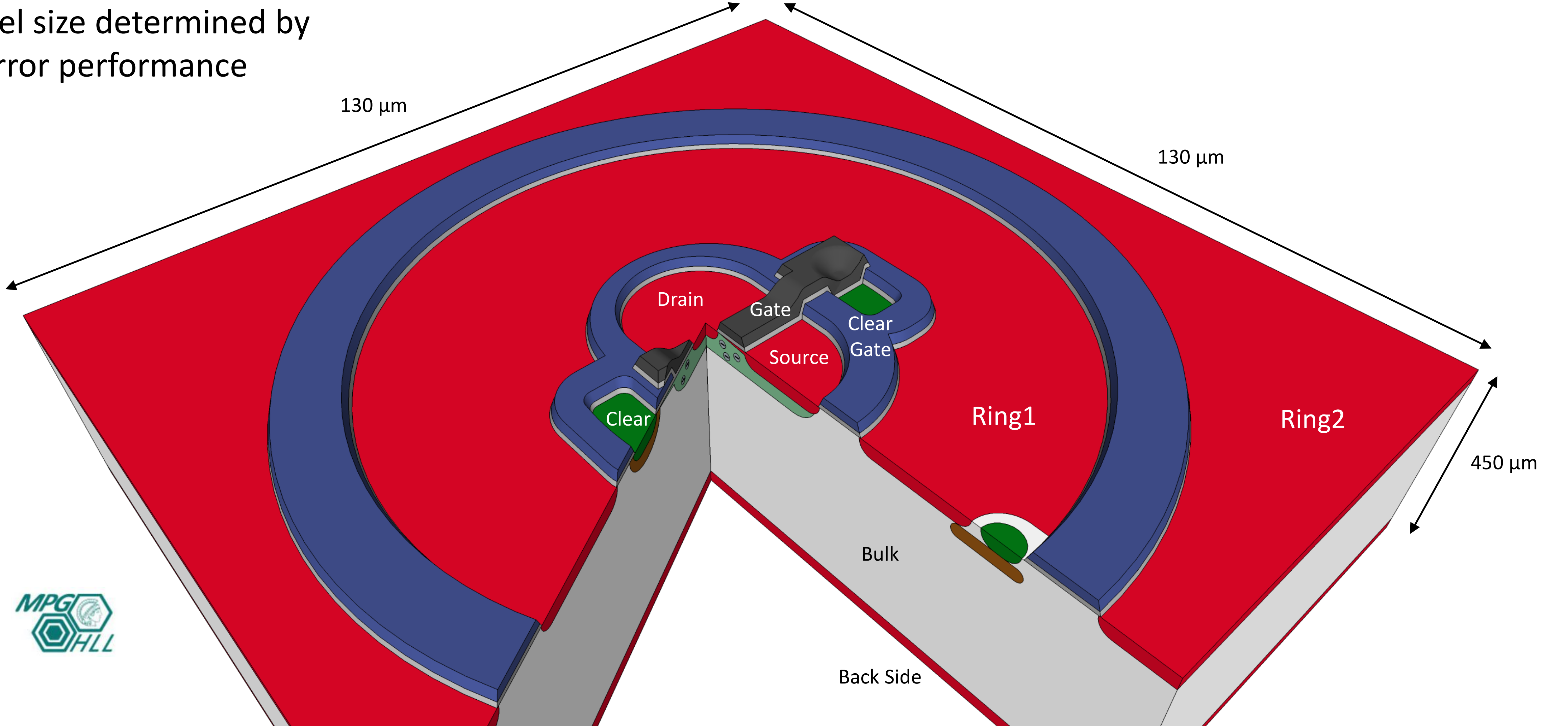
8 x 64-channel Switcher steering ASIC

FEE PCB

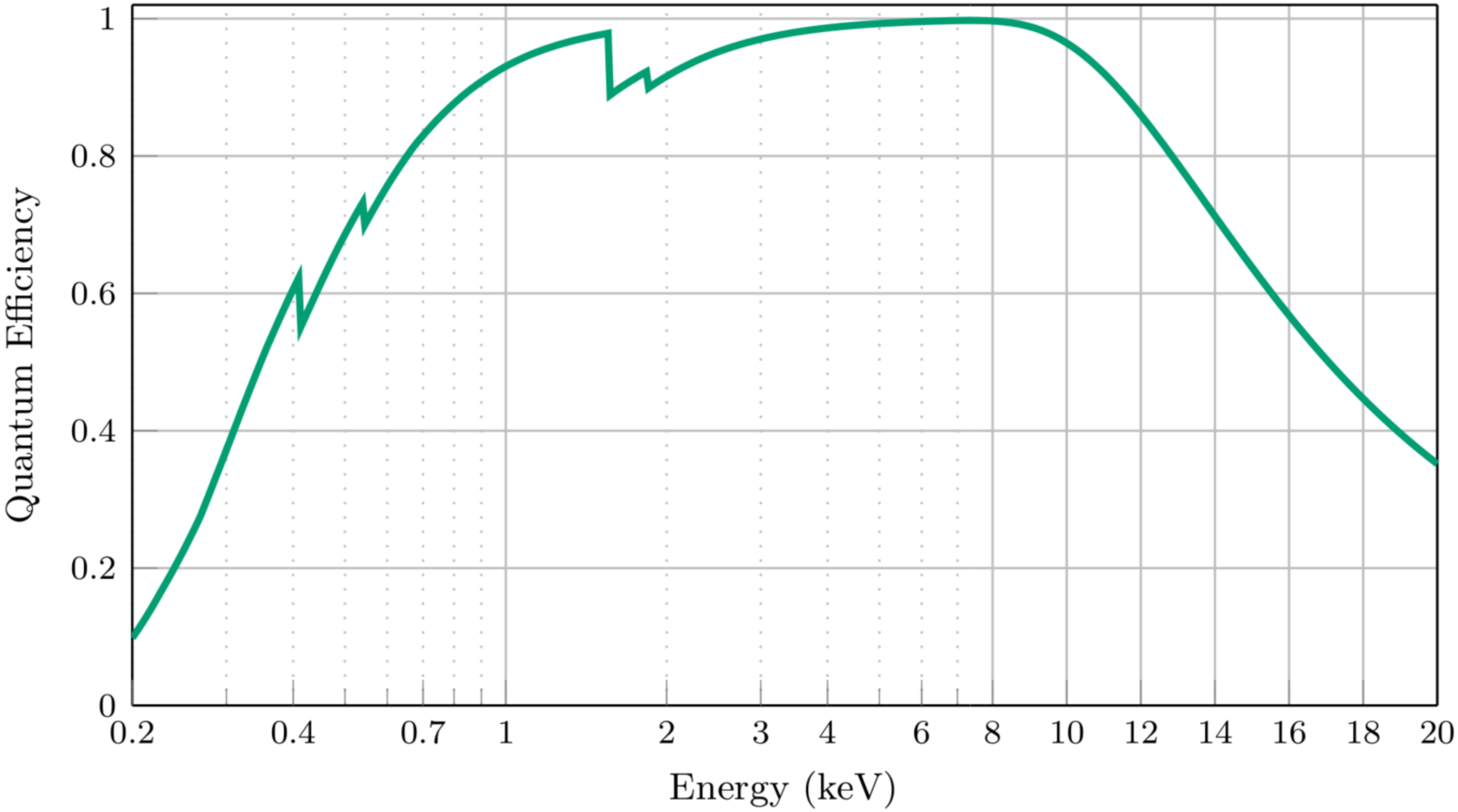
CAD by D. Pietschner

DEPFET Pixel

Pixel size determined by mirror performance



Quantum Efficiency



Theoretical QE for a 450 µm thick silicon sensor with a 90 nm aluminium on-chip filter

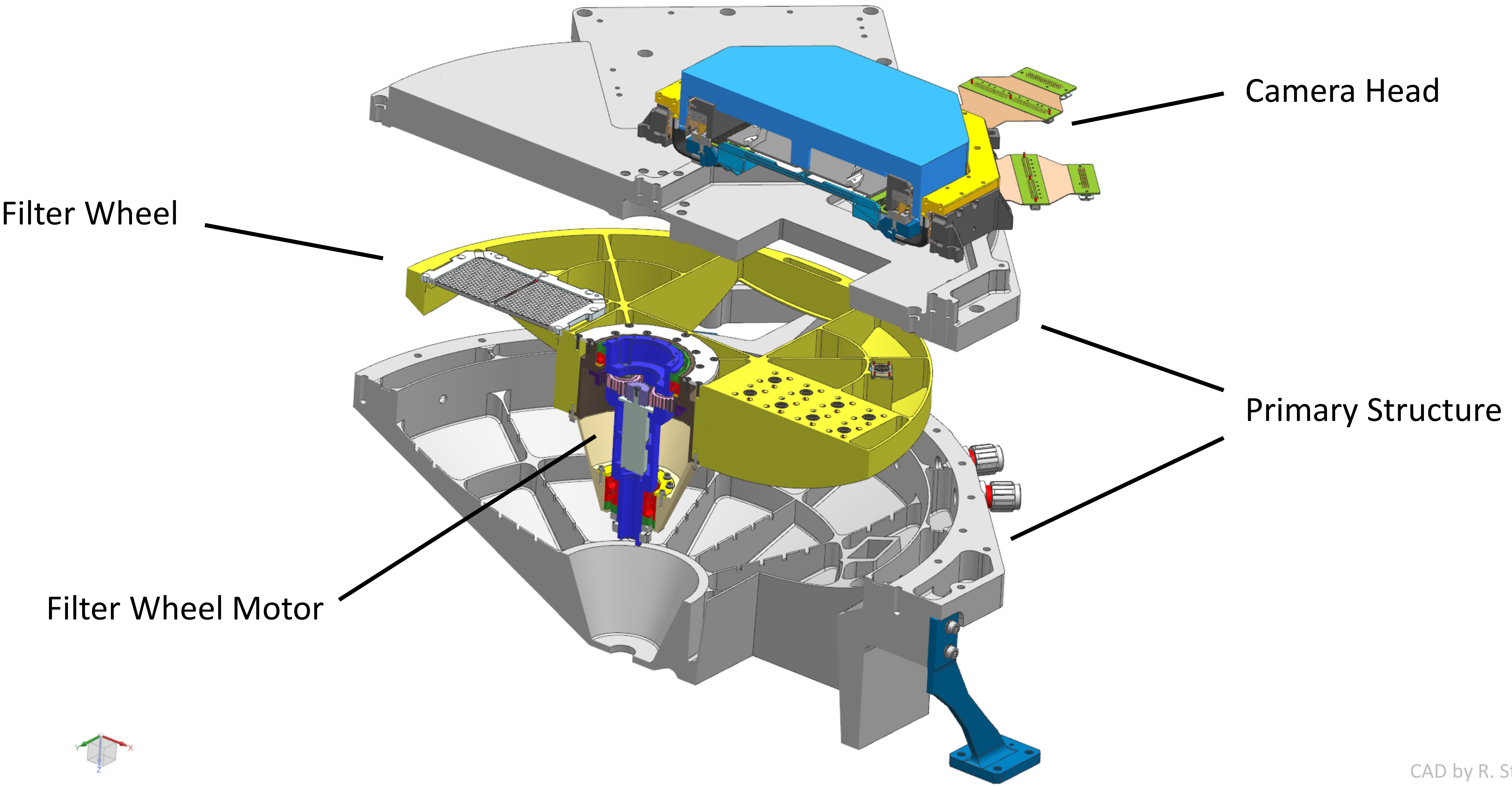
Detector Electronics (WFI on Athena)

DE consists of 3 parts

- GIM: Galvanic Isolation Module
  - Galvanic isolation to the spacecraft
  - Redistribution of the 50 V coming from the spacecraft
- PCM: Power Conditioning Module
  - Detector power supplies
- FPM: Frame Processing Module
  - Digital detector steering
  - Data digitisation and on-board processing

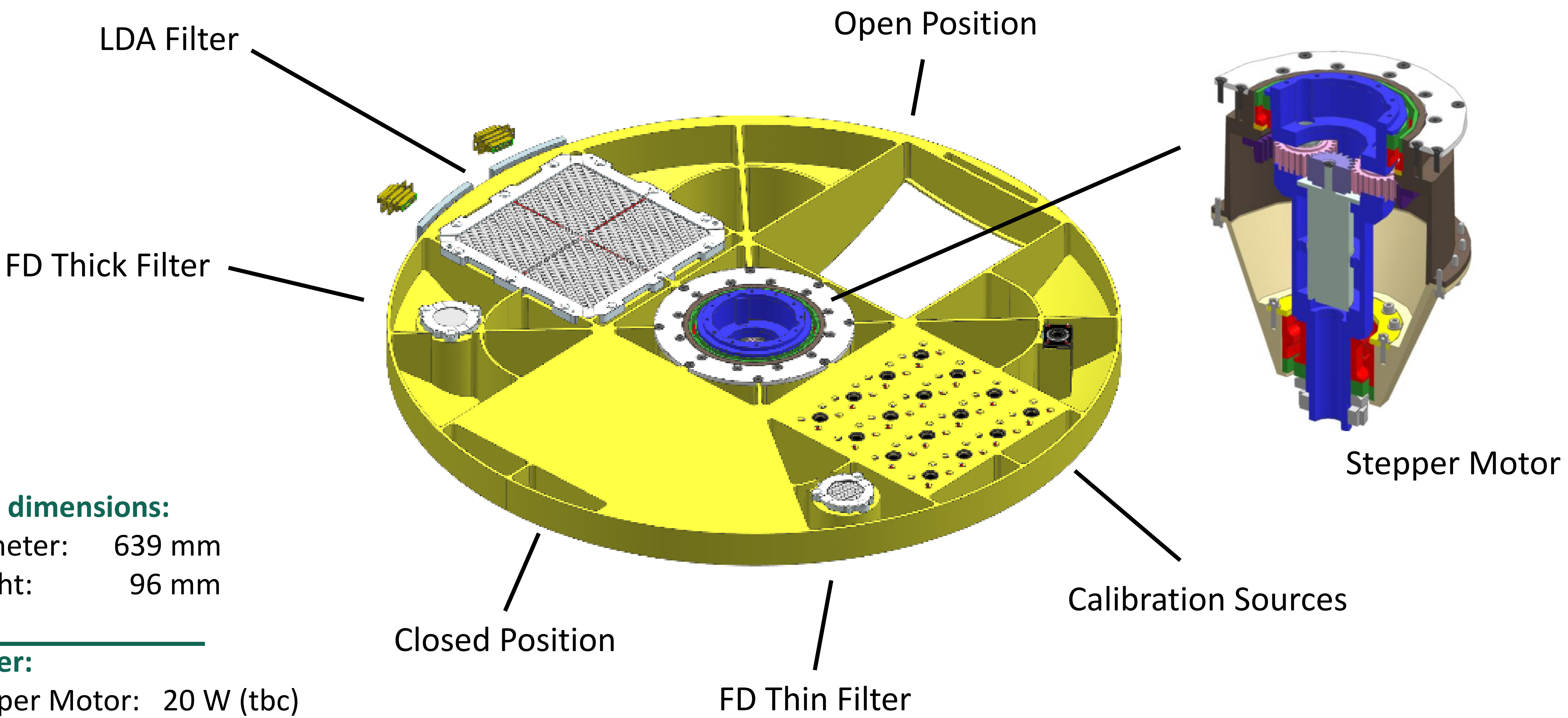
CAD by B. Mican

Primary Structure (WFI on Athena)



CAD by R. Strecker

Filter Wheel (WFI on Athena)



FWA dimensions:

Diameter: 639 mm

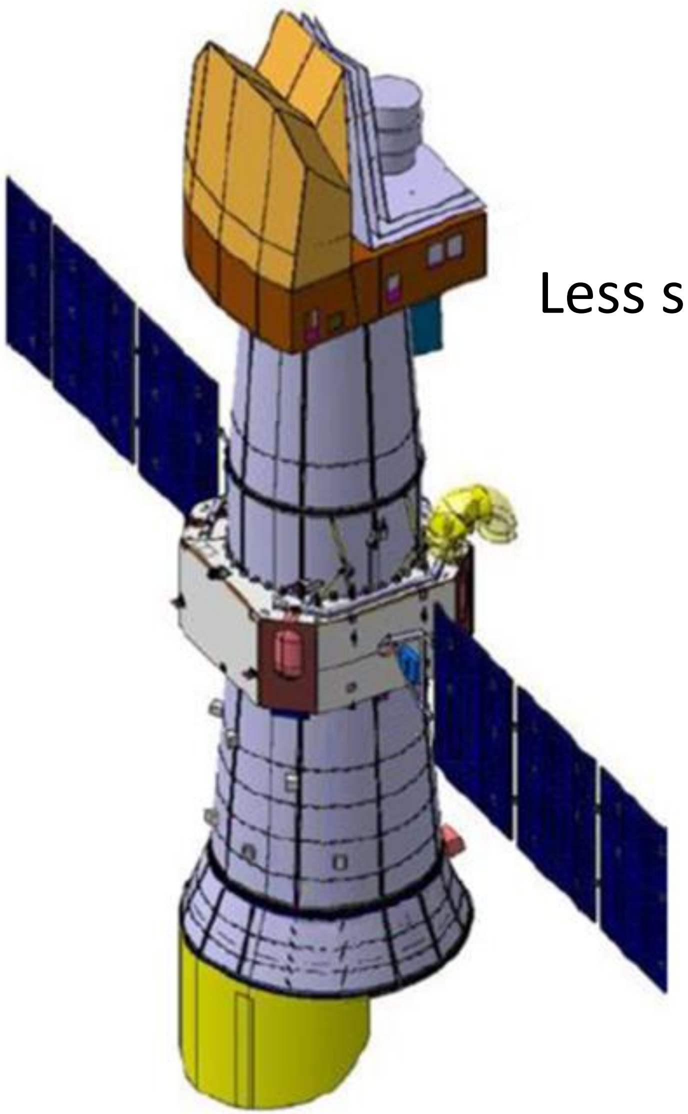
Height: 96 mm

Power:

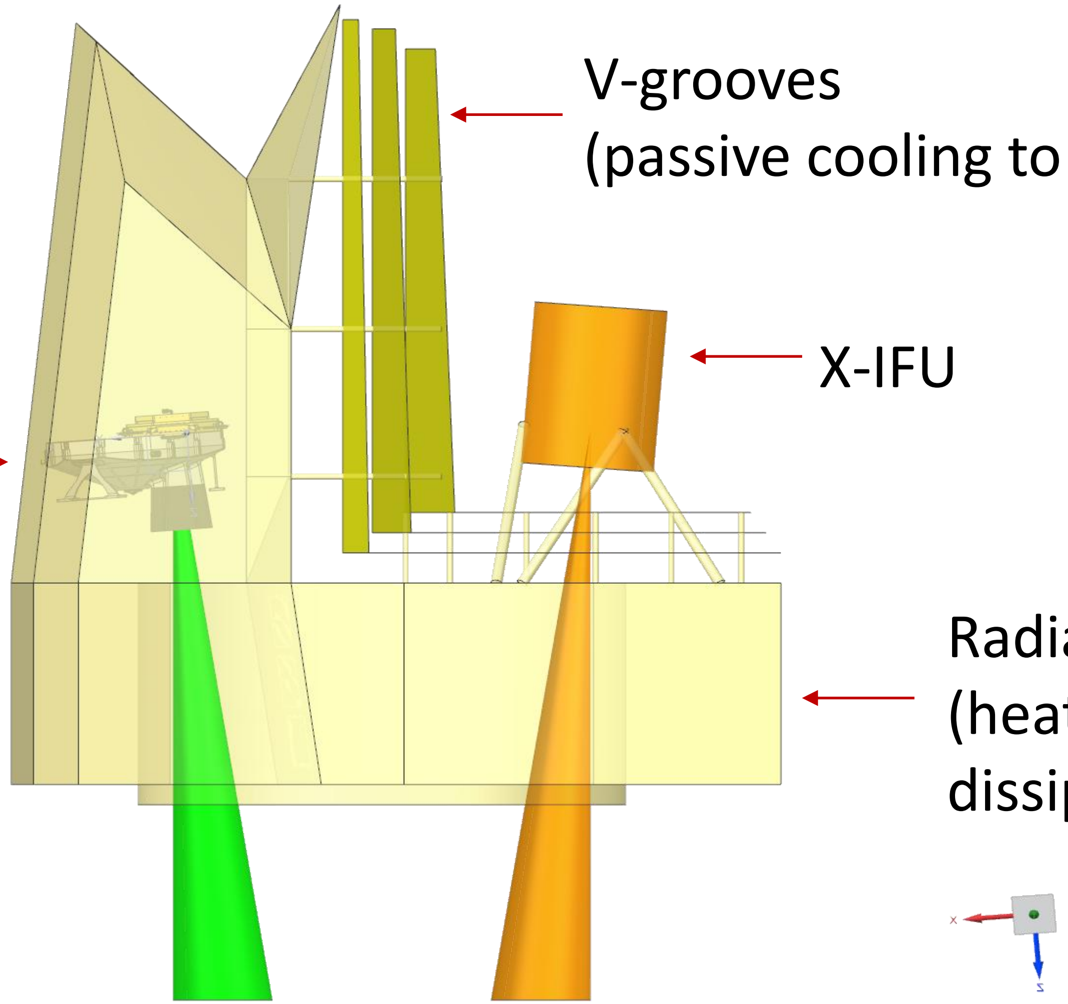
Stepper Motor: 20 W (tbc)

CAD by R. Strecker

NewAthena



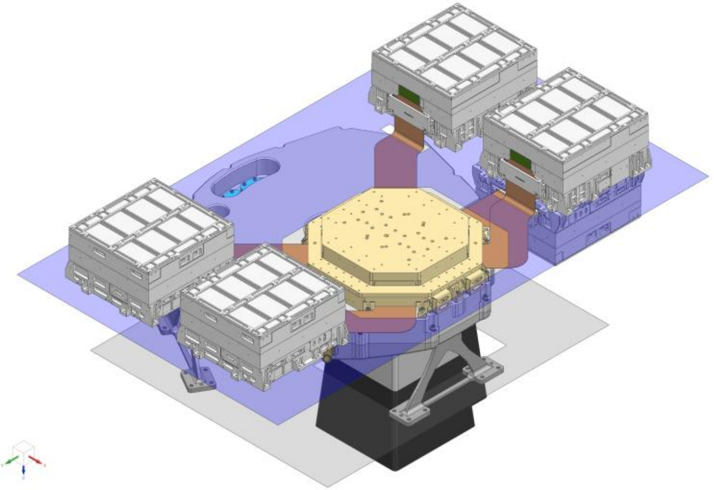
Less space for WFI



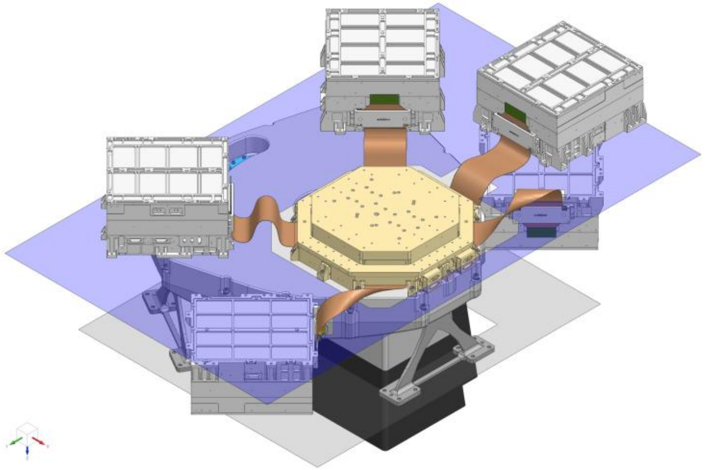
Slide prepared by A. Rau, Material from ESA

WFI on NewAthena

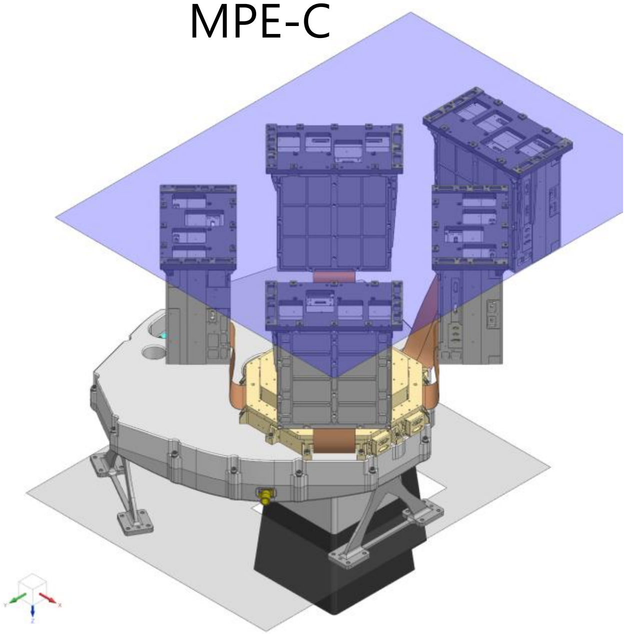
MPE-A



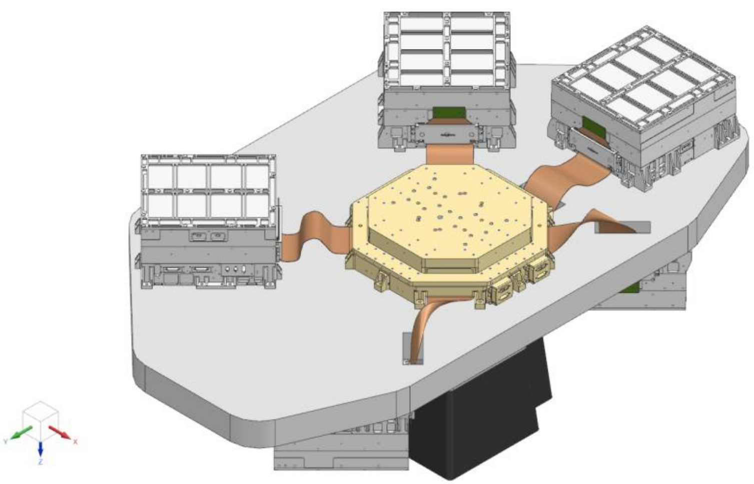
MPE-B



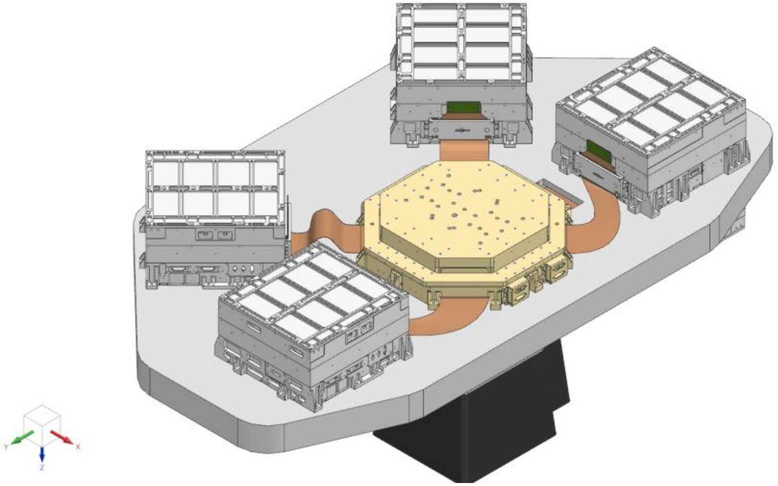
MPE-C



MPE-D

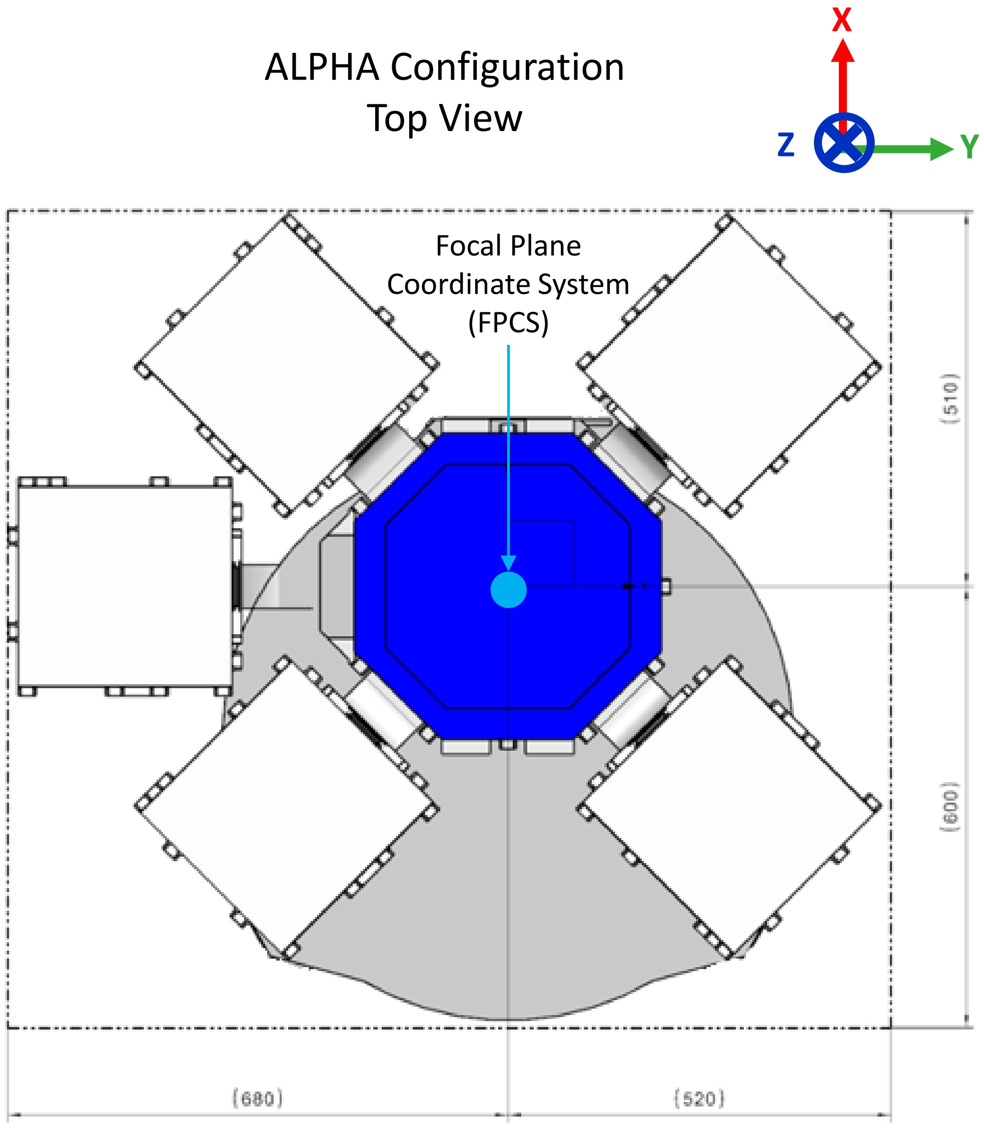


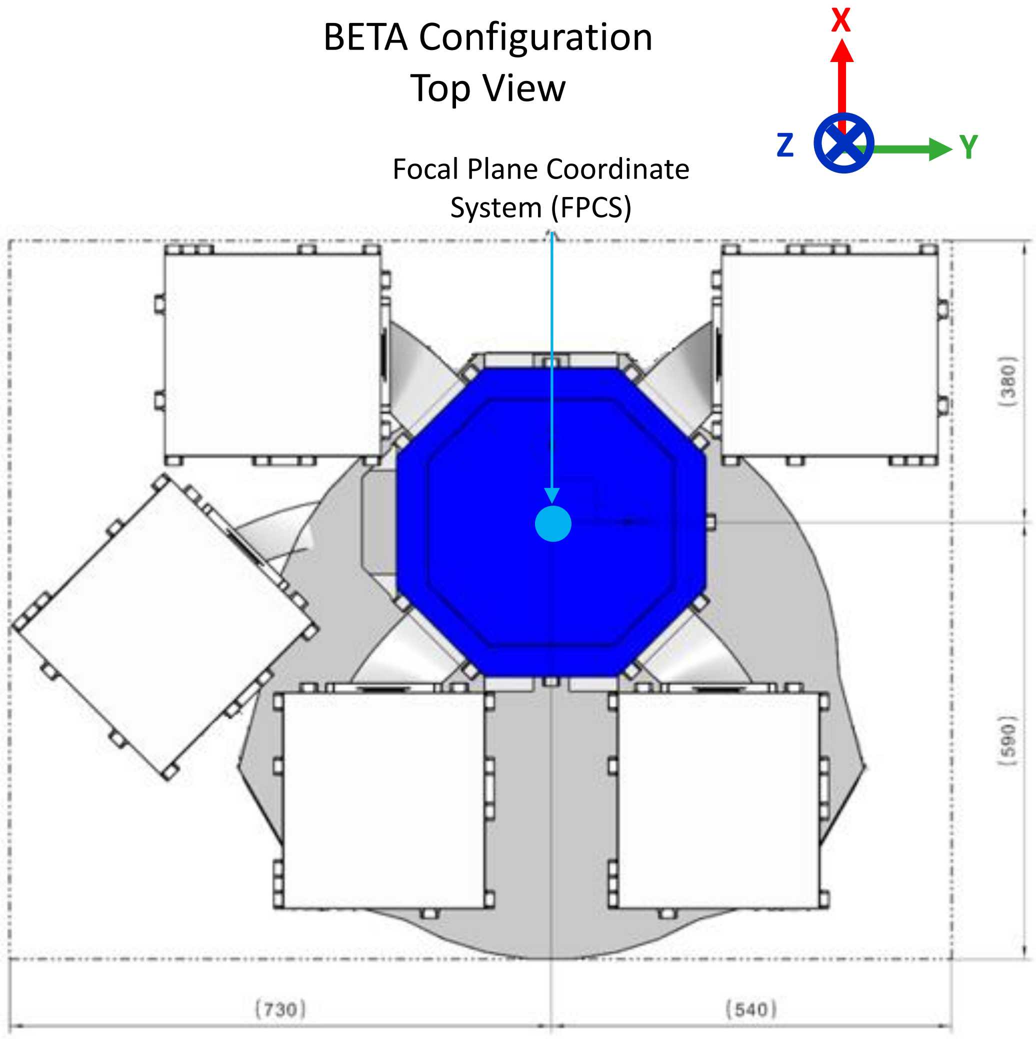
MPE-E



Slide prepared by N. More

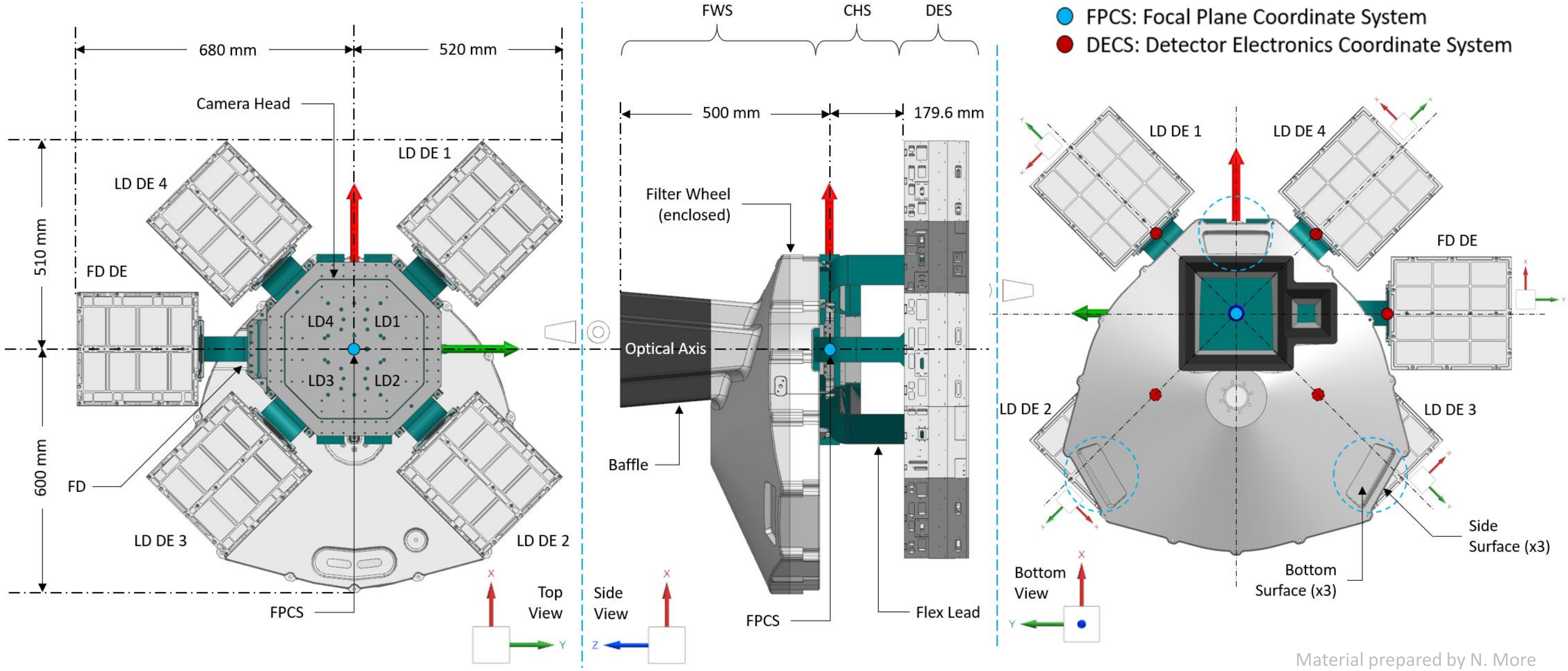
WFI on NewAthena





Slide prepared by N. More

WFI on NewAthena



Material prepared by N. More

DEPFET Prototyping (PXD 11)

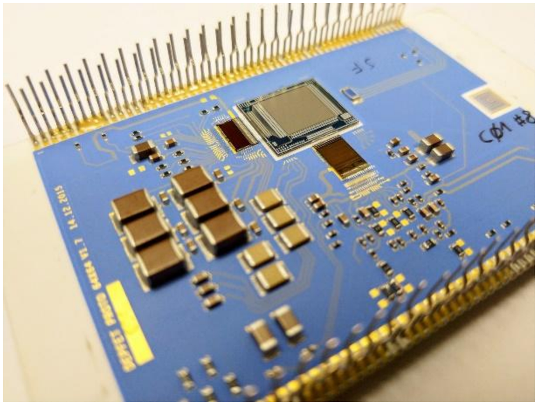
MAX PLANCK SEMICONDUCTOR LABORATORY

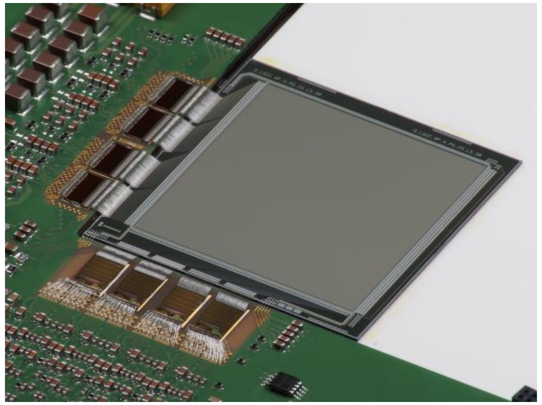
Prototype DEPFETs (64 x 64 pixels):

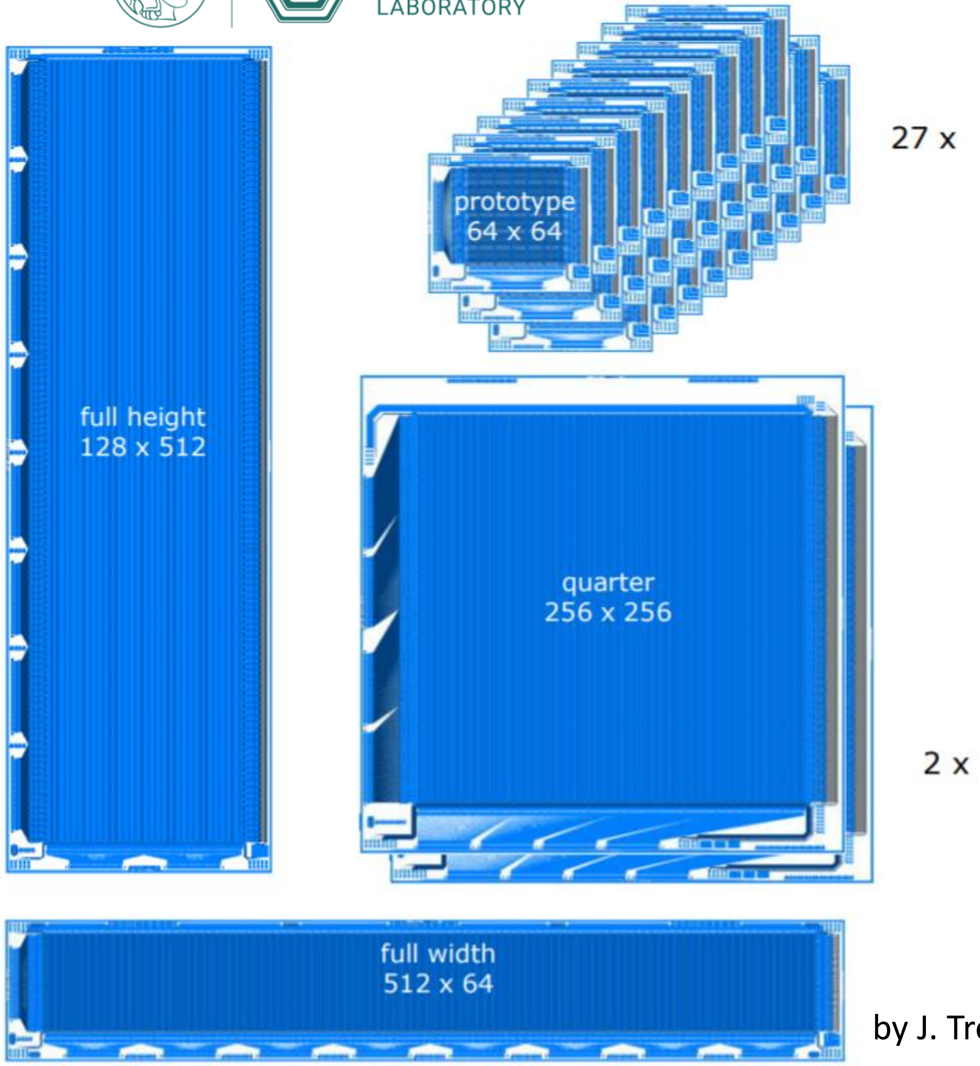
- 17 different DEPFET design variations
- 7 different fabrication technology options
- 2 different readout modes

Larger Arrays:

- test full capacity of a row/column connected to an ASIC
- test homogeneity of a larger number of pixels

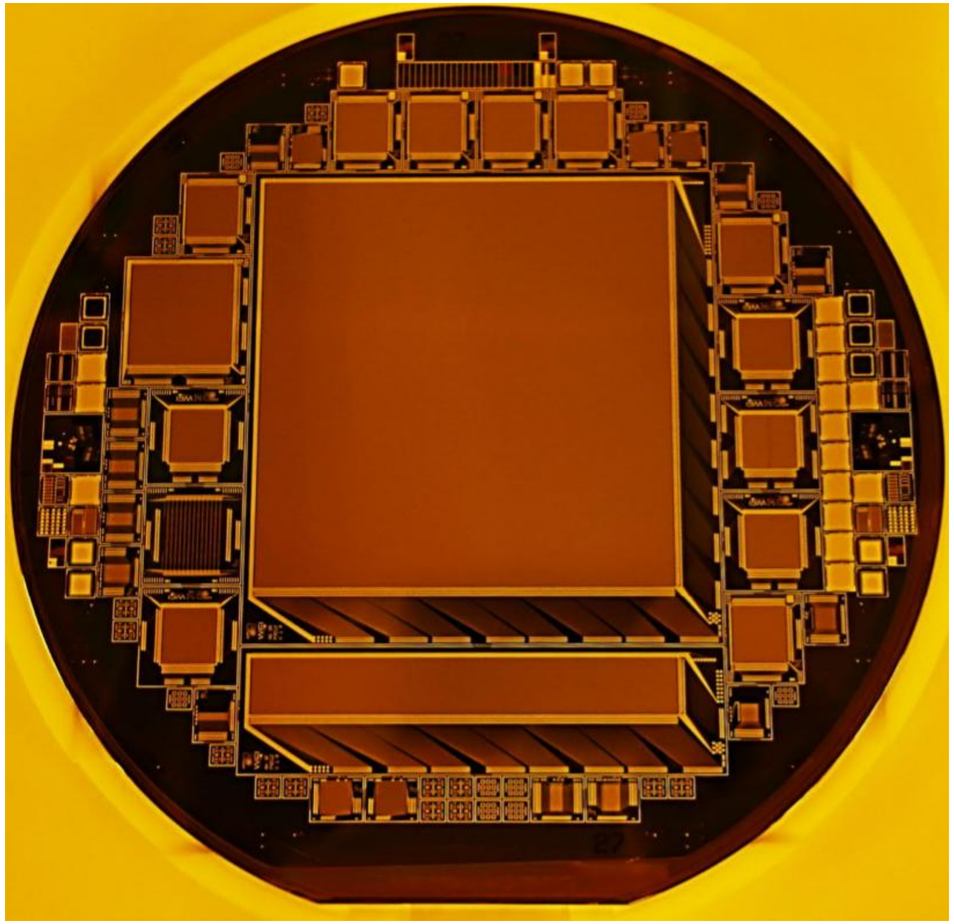






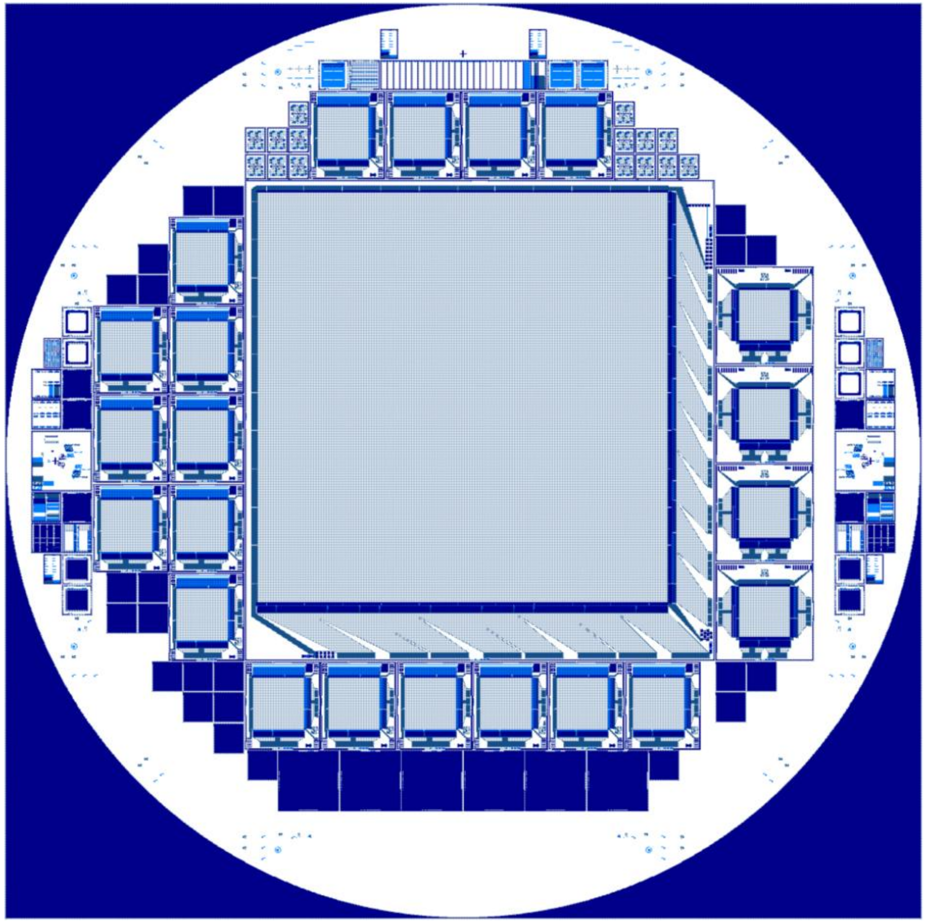
by J. Treis

DEPFET Pre-Flight (PXD 12) and Flight Production (PXD 14)



MAX PLANCK SEMICONDUCTOR LABORATORY

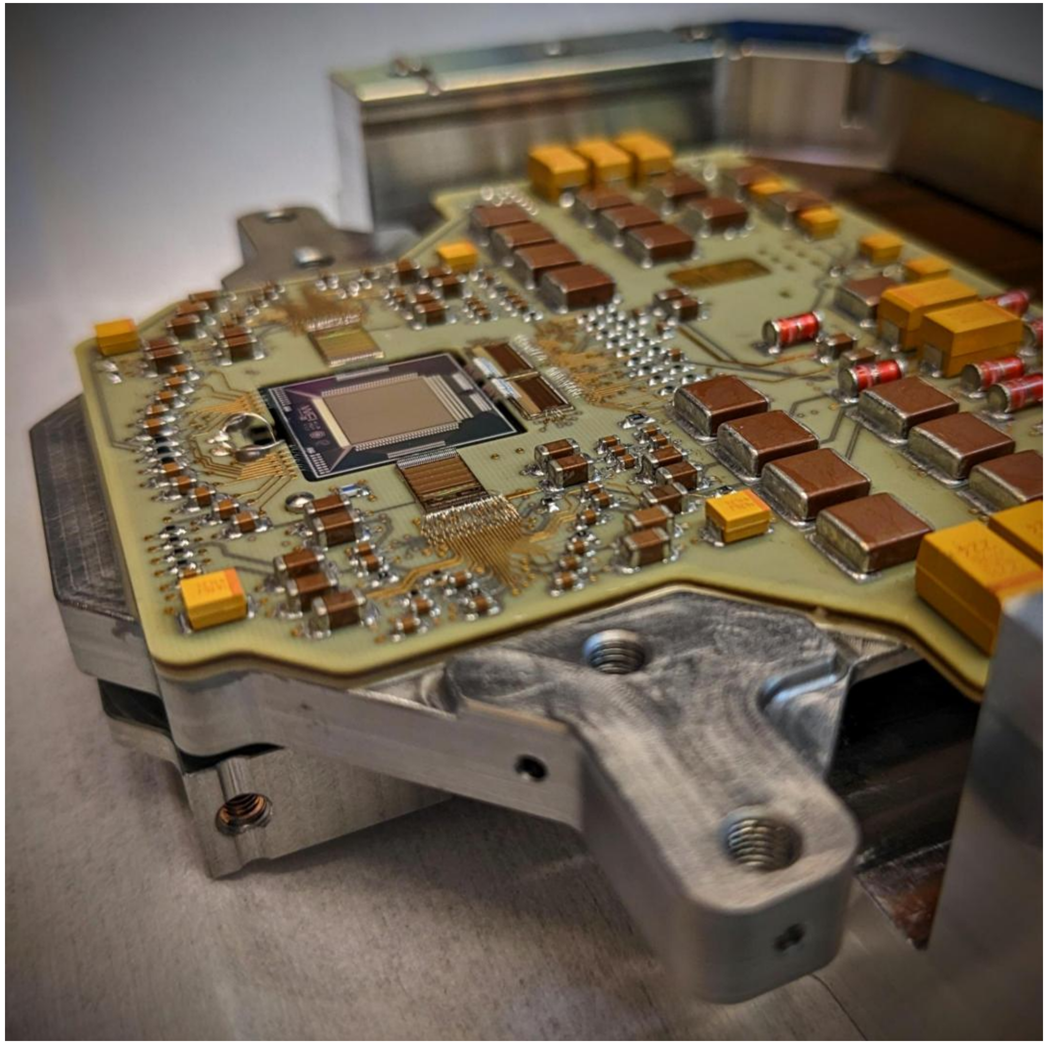
by P. Lechner



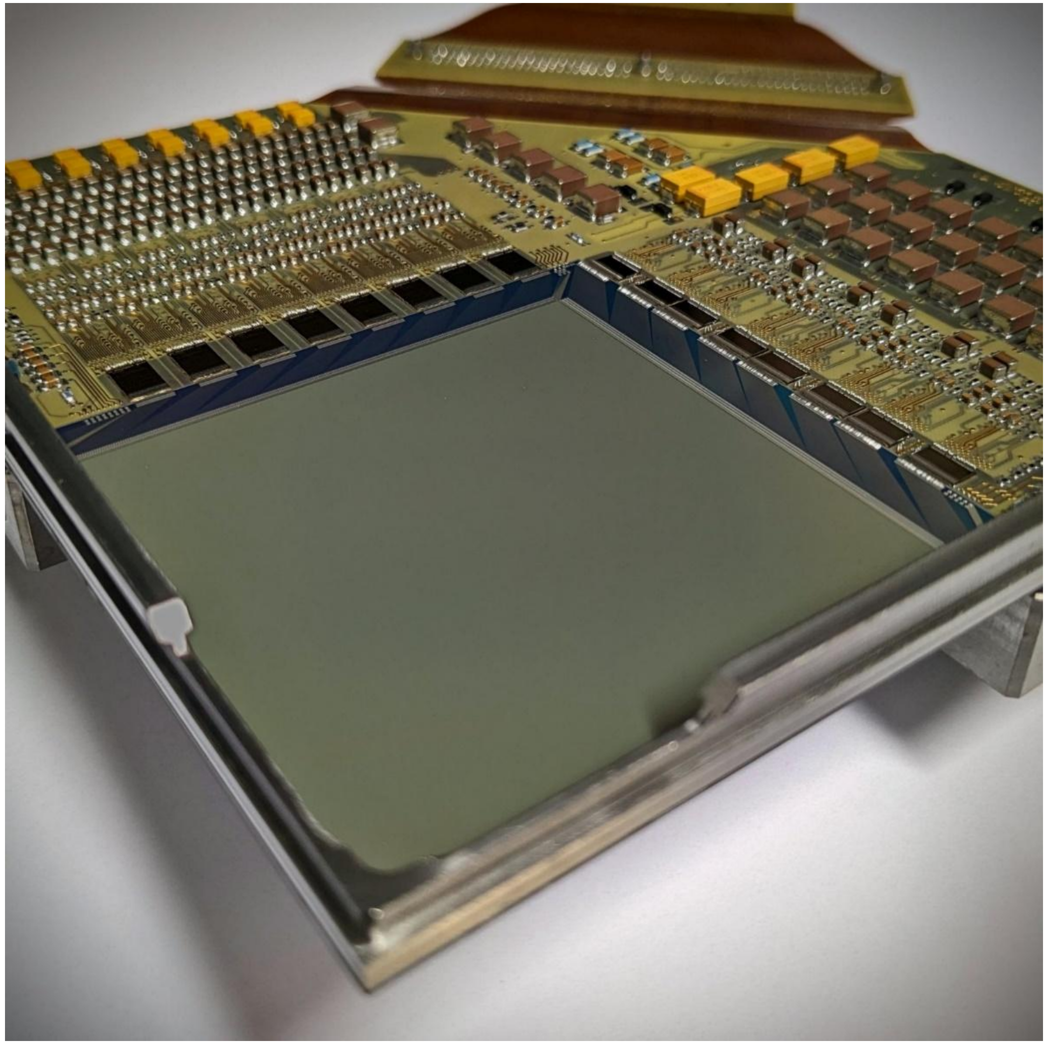
- Full DEPFET sensor size (LD and FD)
- Final DEPFET layout & fabrication technology
- Learning for flight production

- "Mass" production: 36 wafers in 3 batches
- 1 LD, 4 FDs, 18 prototype DEPFETs, diodes
- first wafers finished

DEPFET Detector Modules (PXD 12)

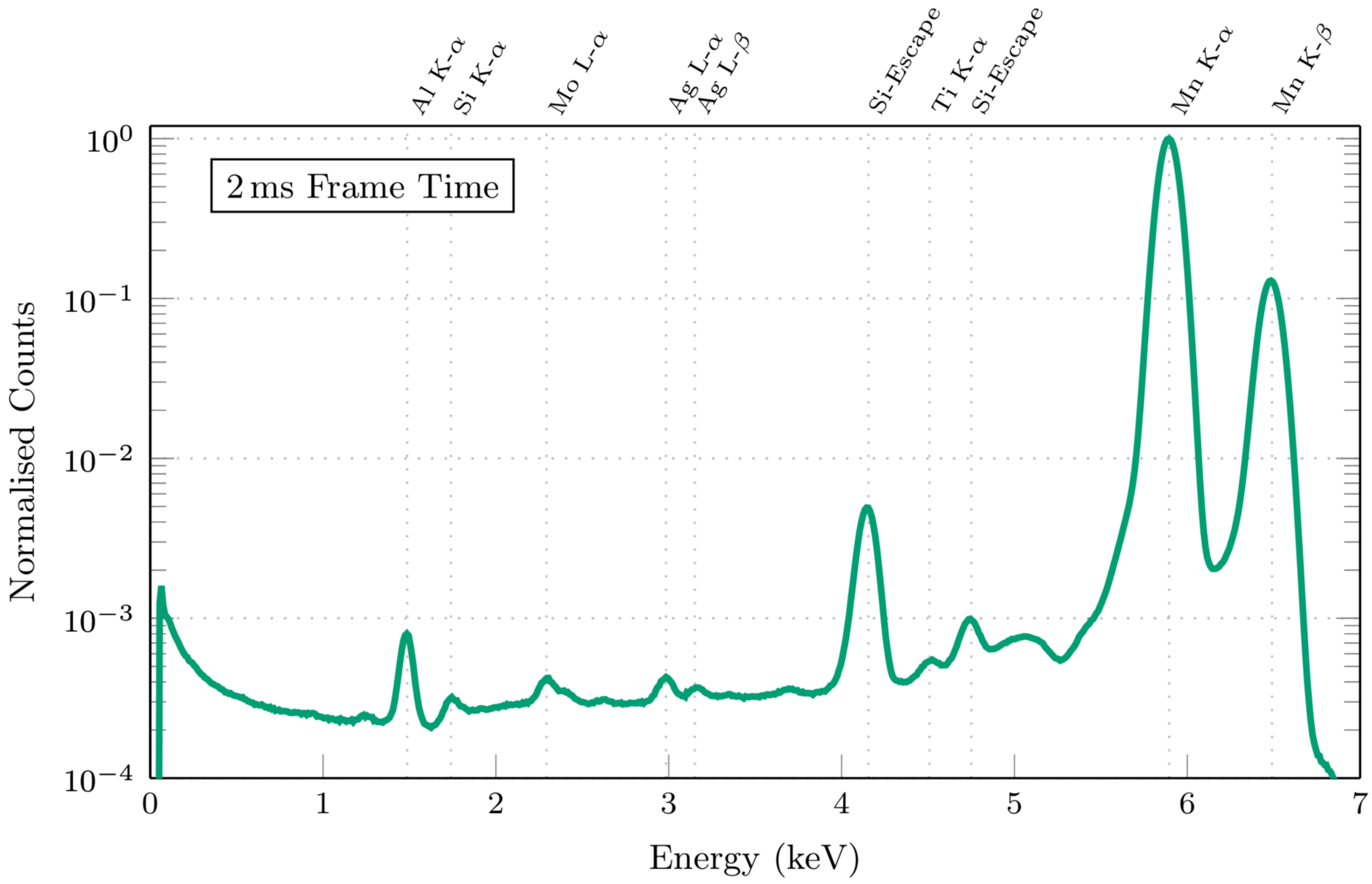


Fast Detector



Large Detector

DEPFET Detector Performance (PXD 12)



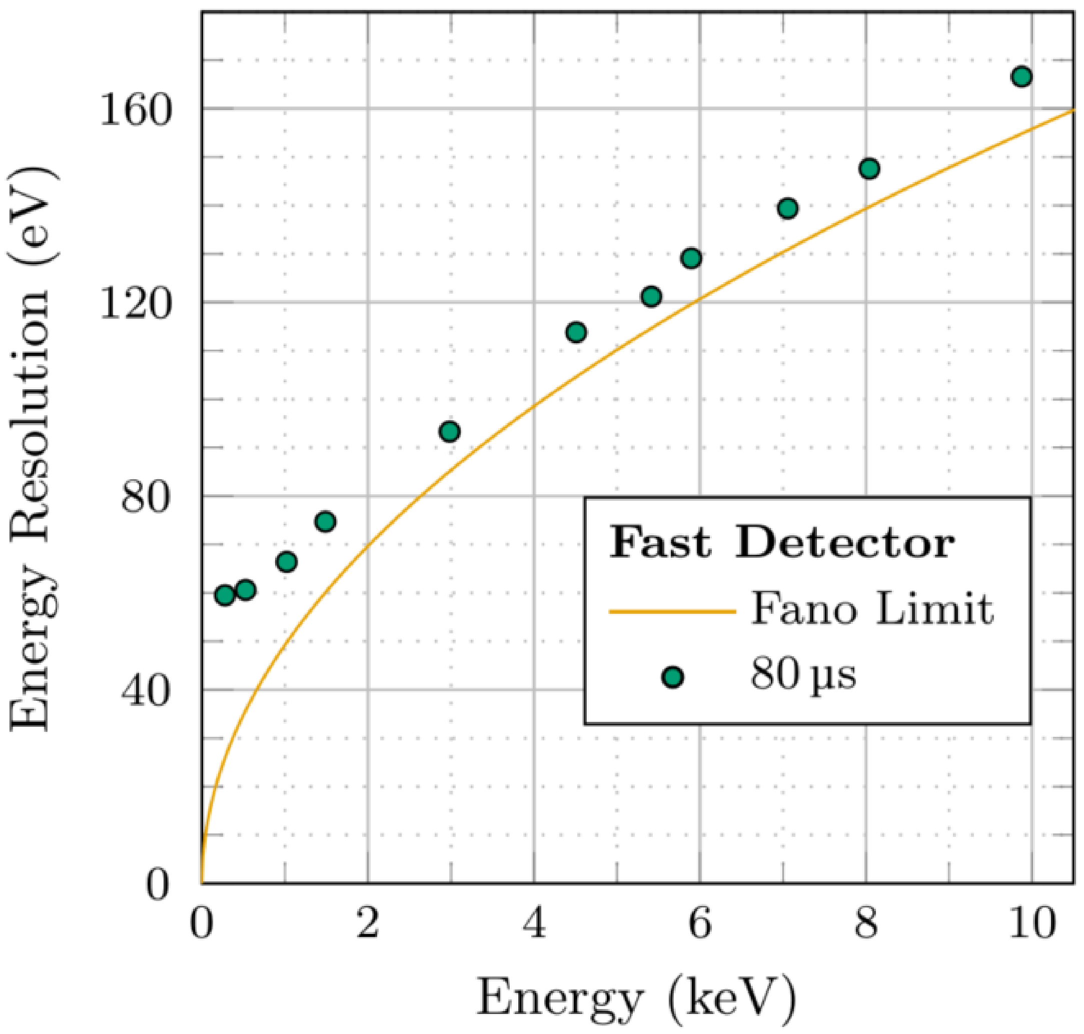
Large Detector

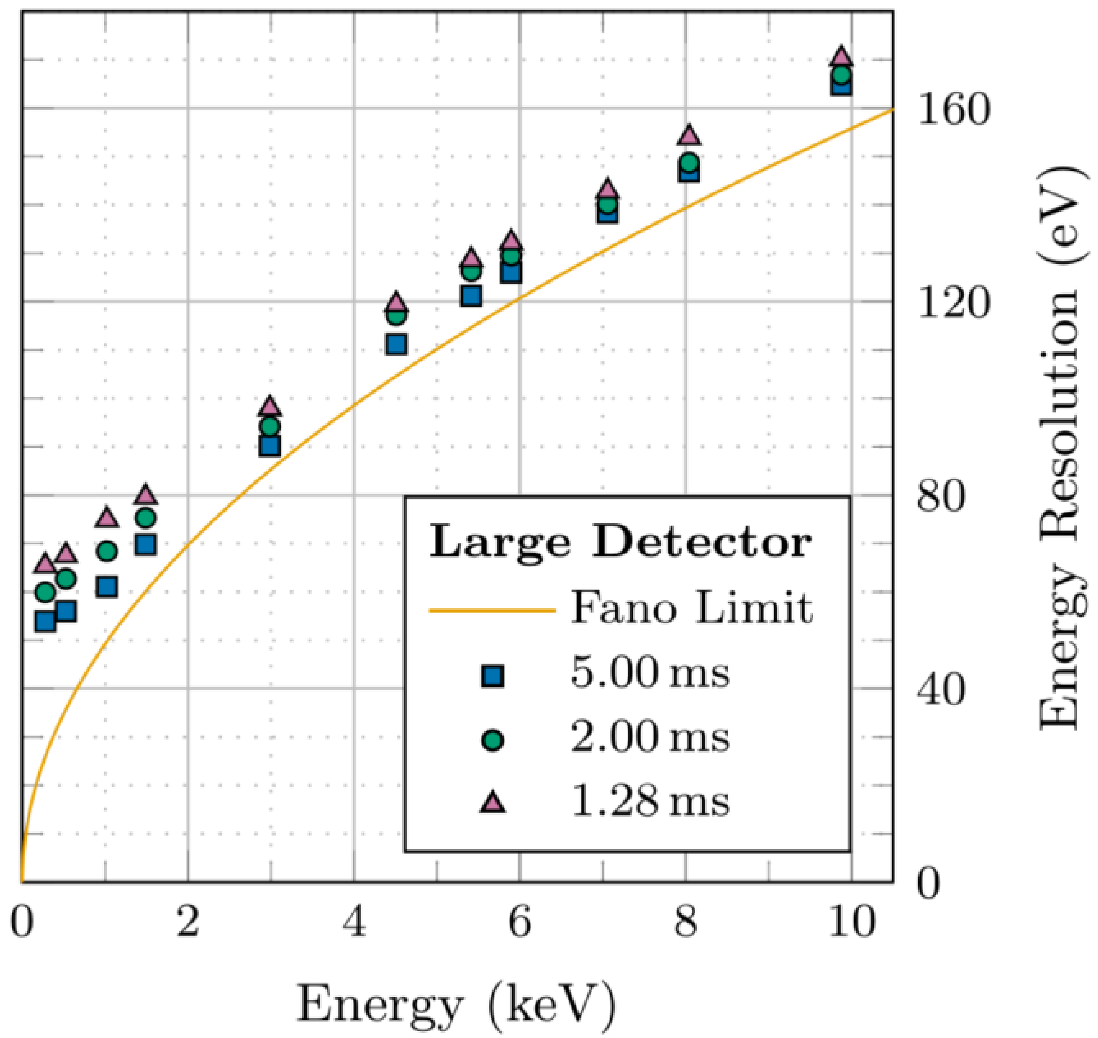
Pre-Flight

2 ms per frame

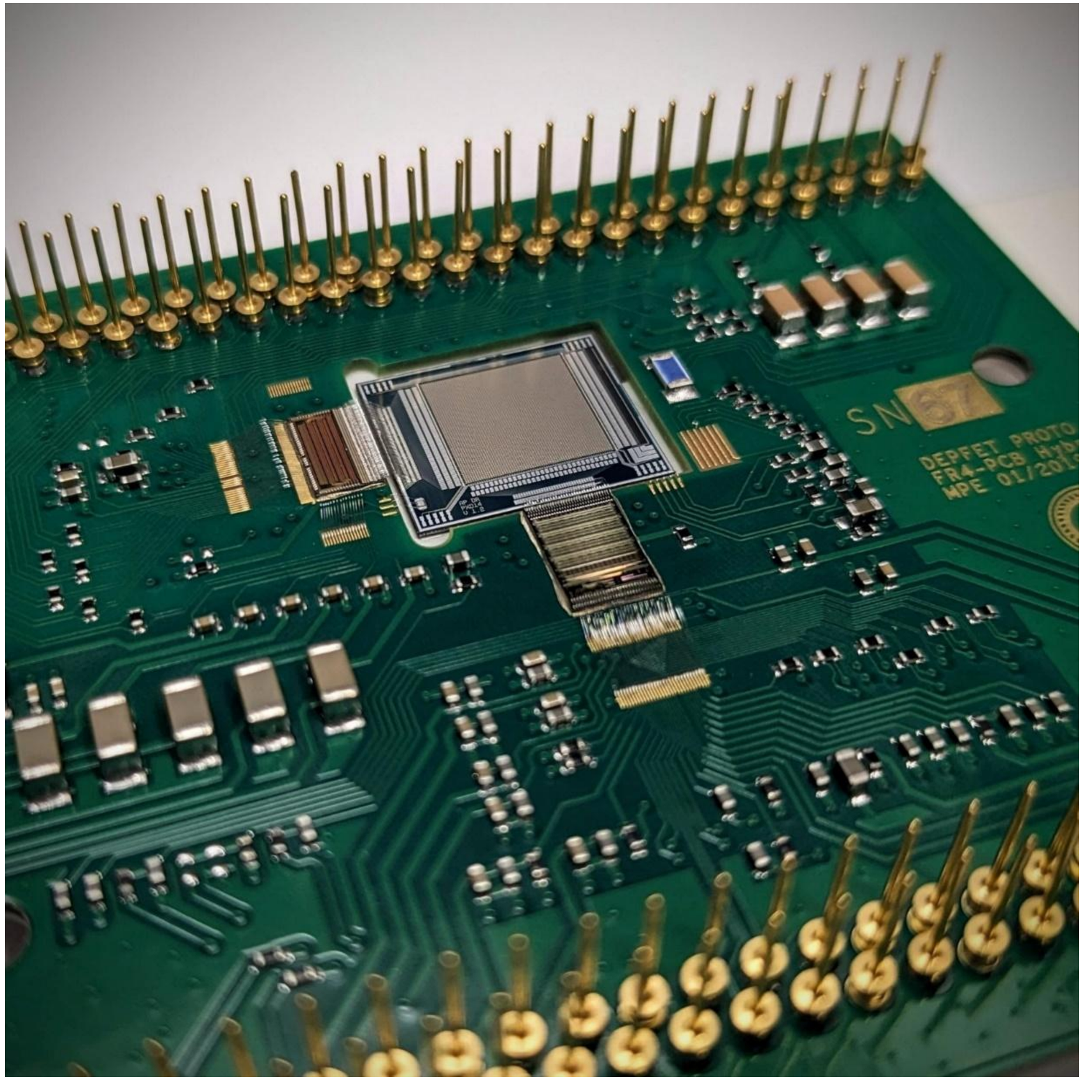
131 eV energy resolution at 5.9 keV

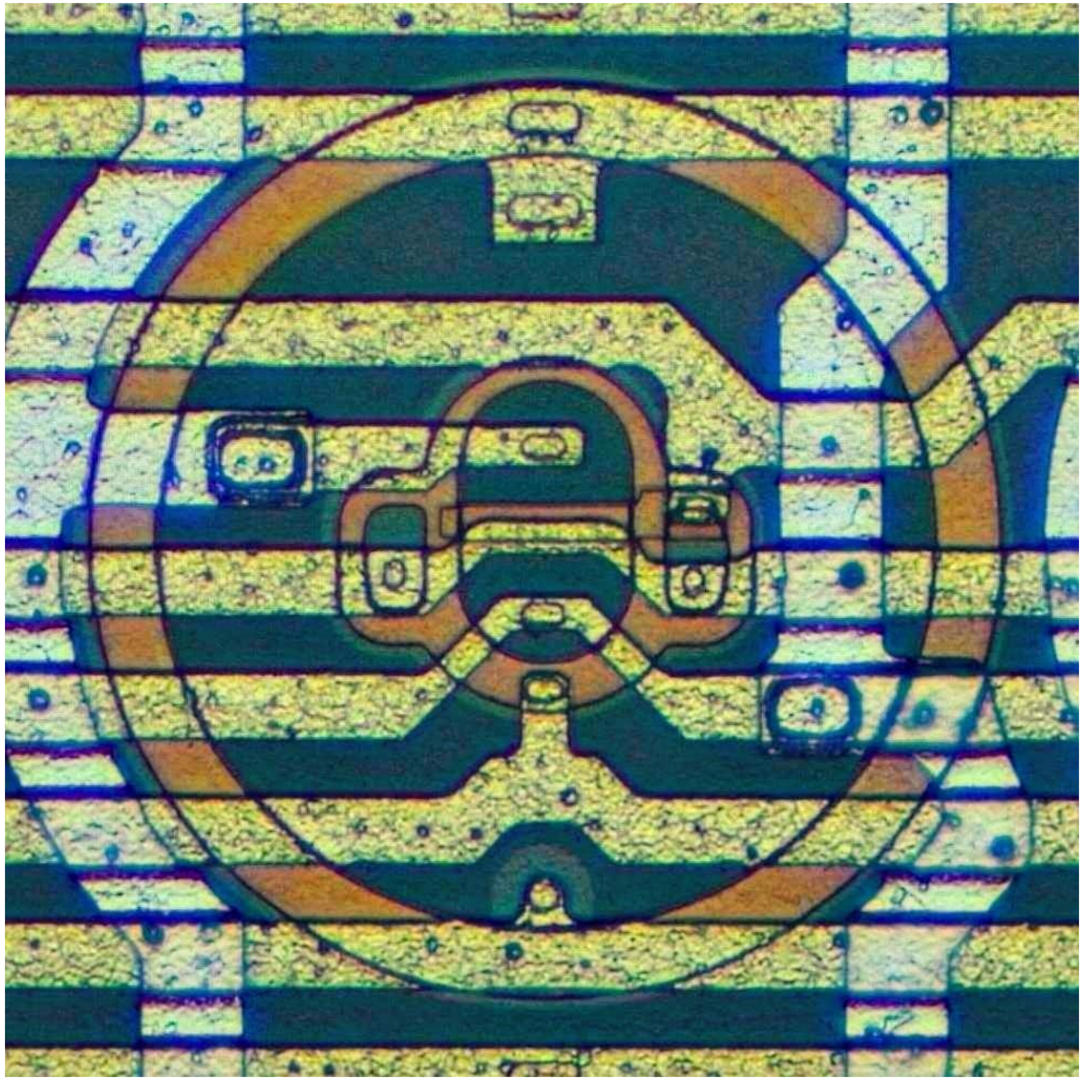
DEPFET Detector Performance (PXD 12)





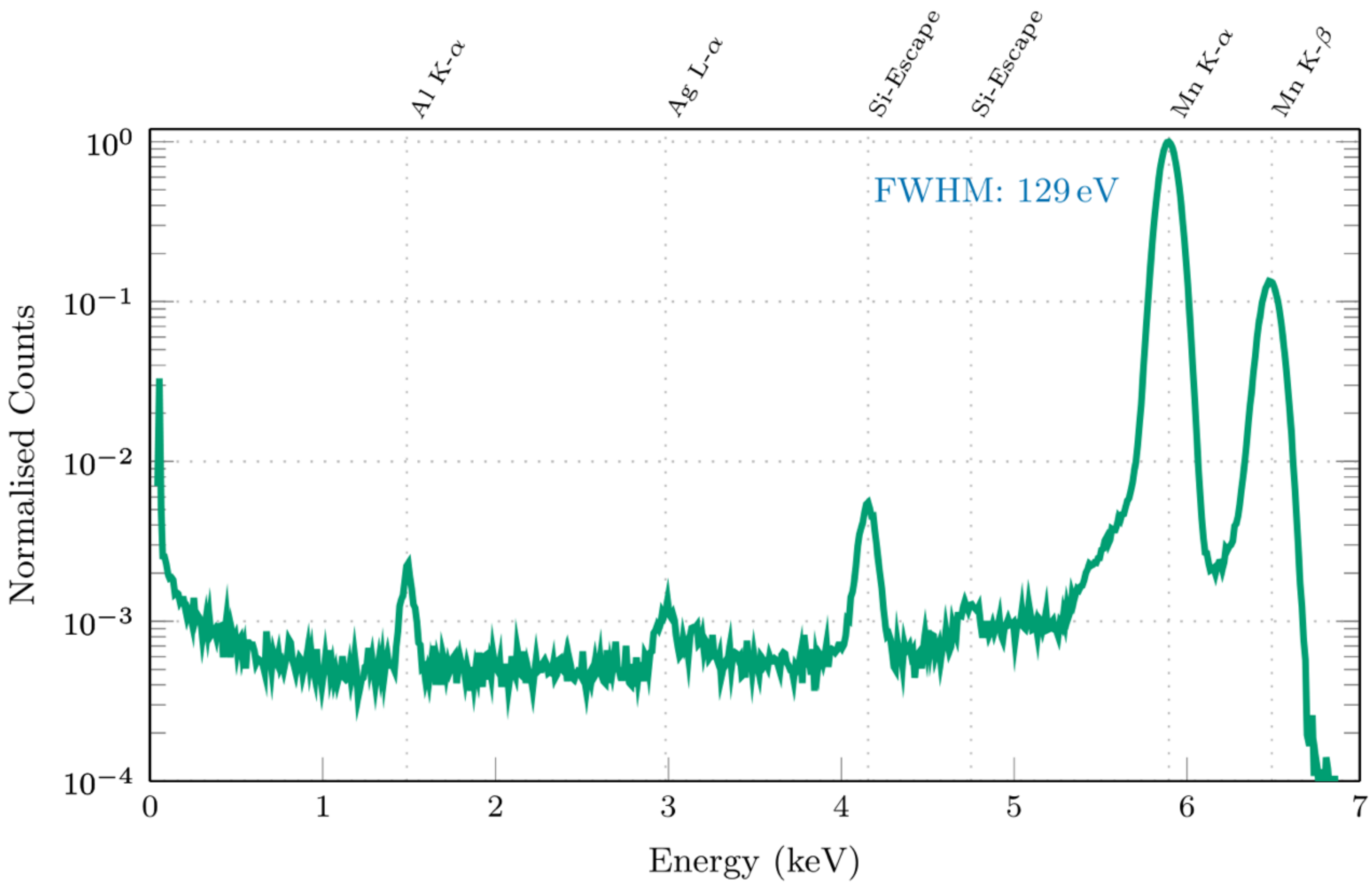
Flight Production DEPFETs (PXD 14)





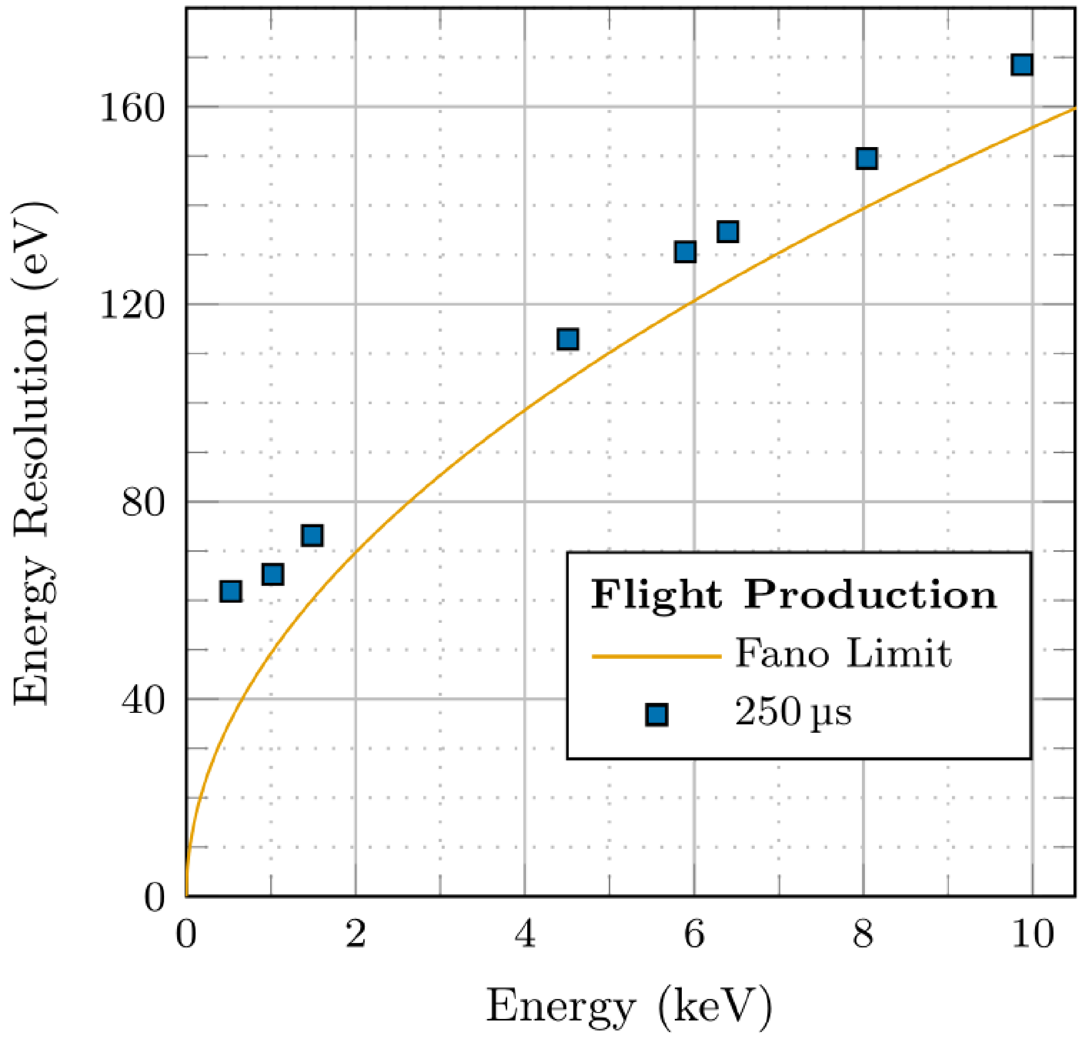
DEPFET Detector Performance (PXD 14)

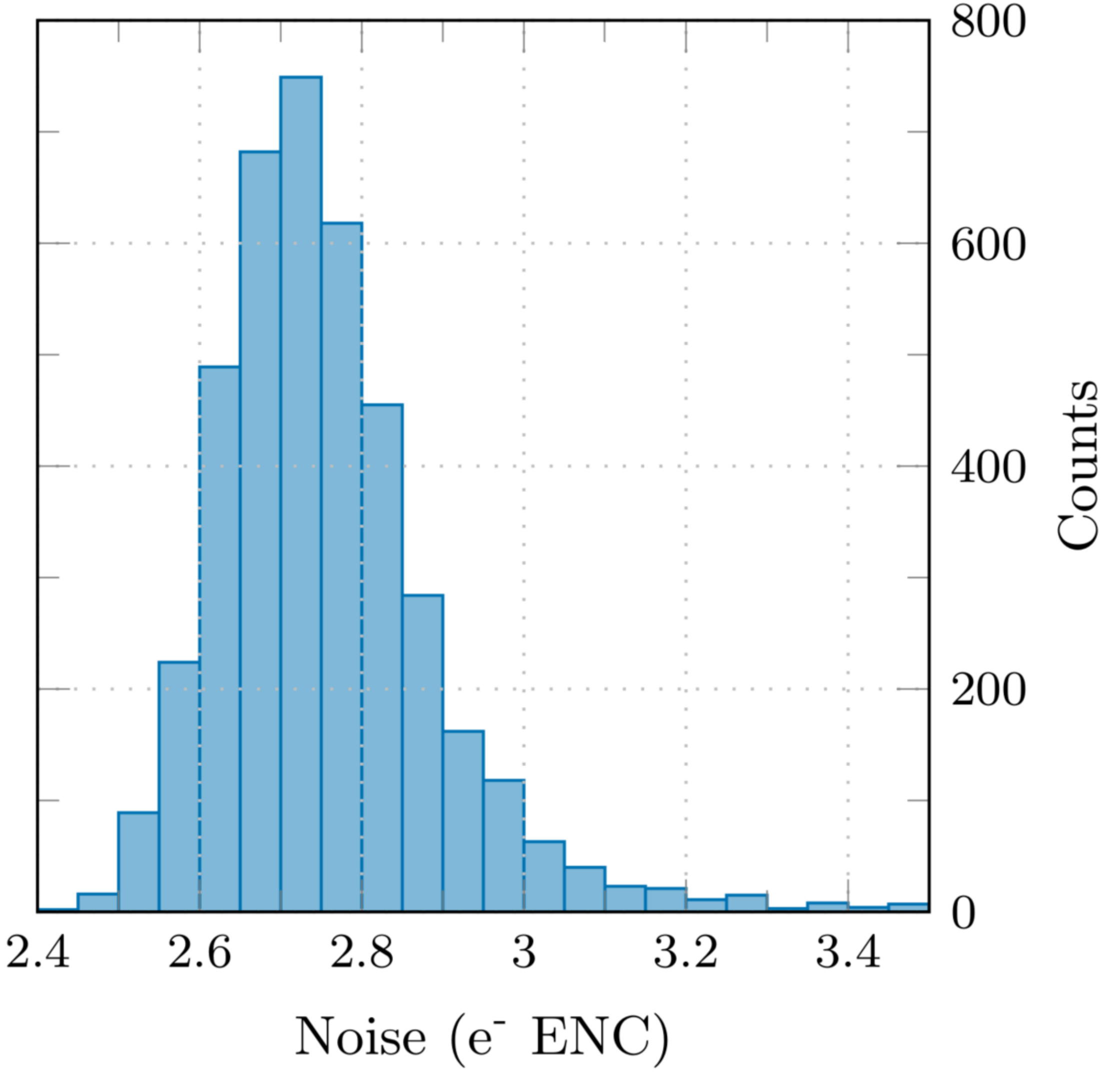
64 x 64 Pixel DEPFET



DEPFET Detector Performance (PXD 14)

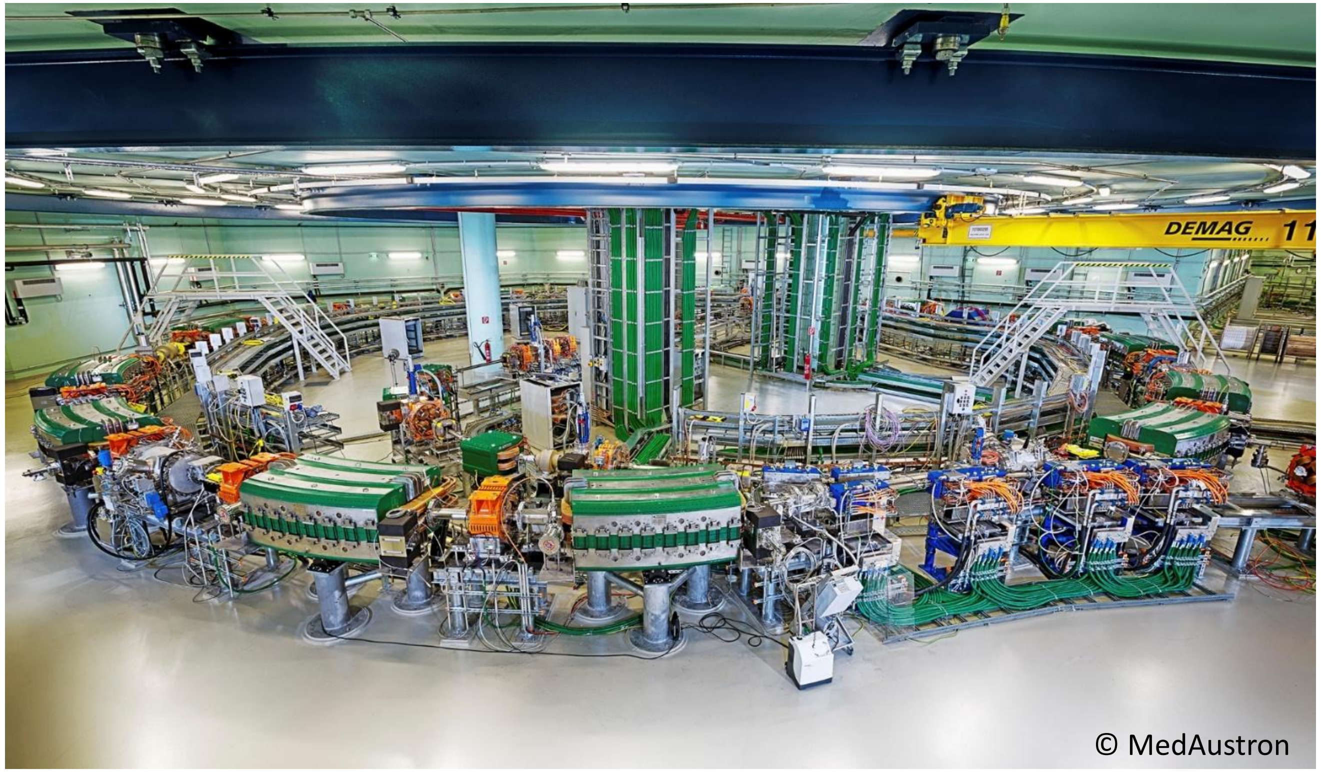
64 x 64 Pixel DEPFET

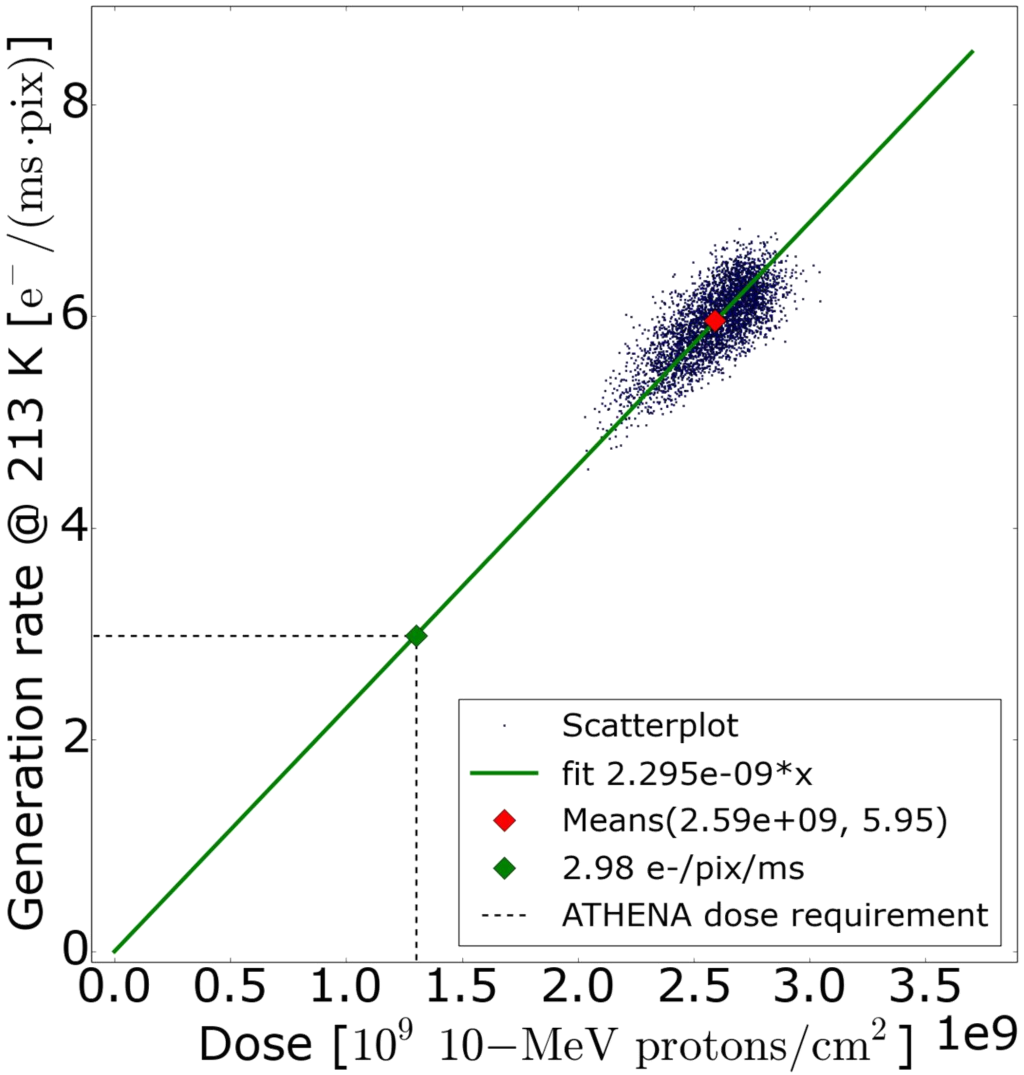




DEPFET Sensor Degradation

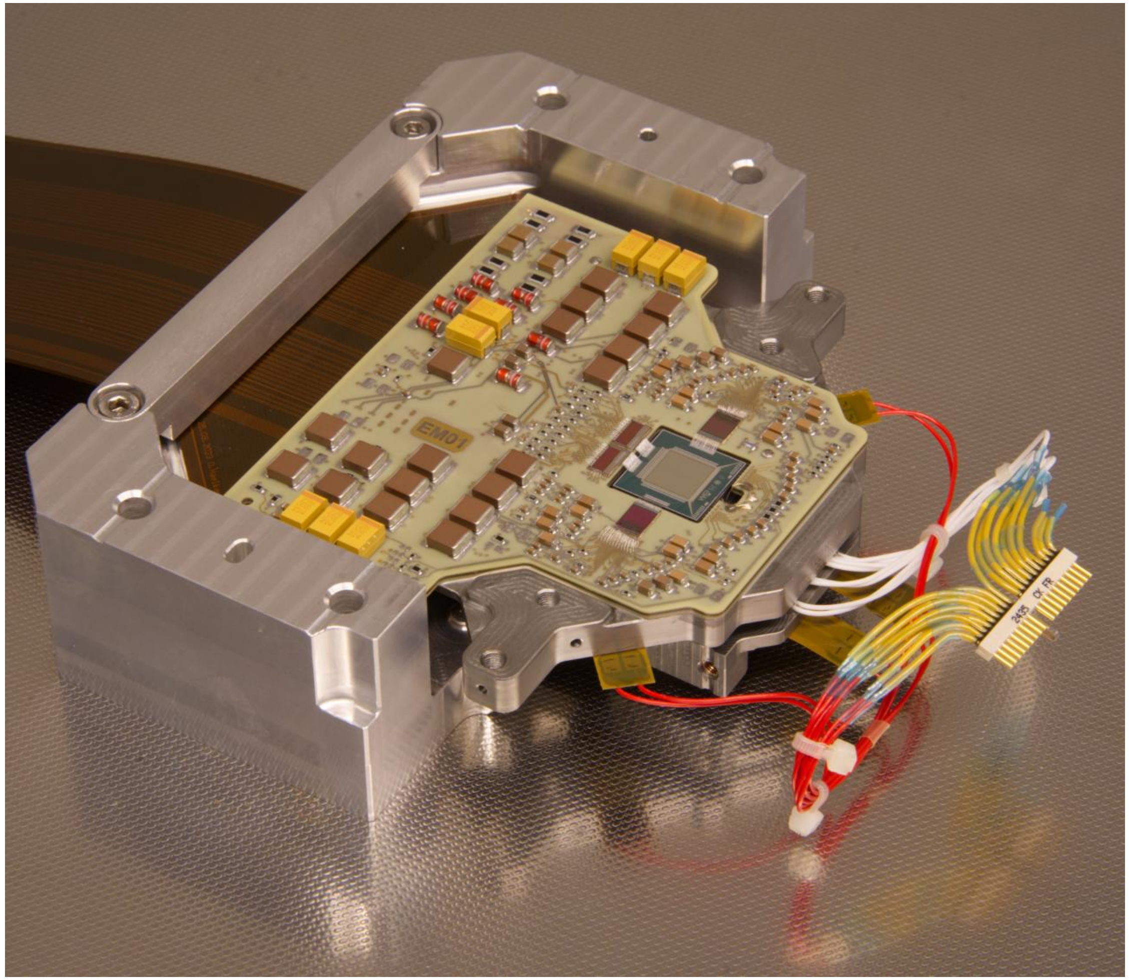
- Proton irradiation campaign at MedAustron with a DEPFET sensor from the flight production to study the impact of defects due to radiation damage
- Has an impact on the required sensor temperature at the end of life of the mission



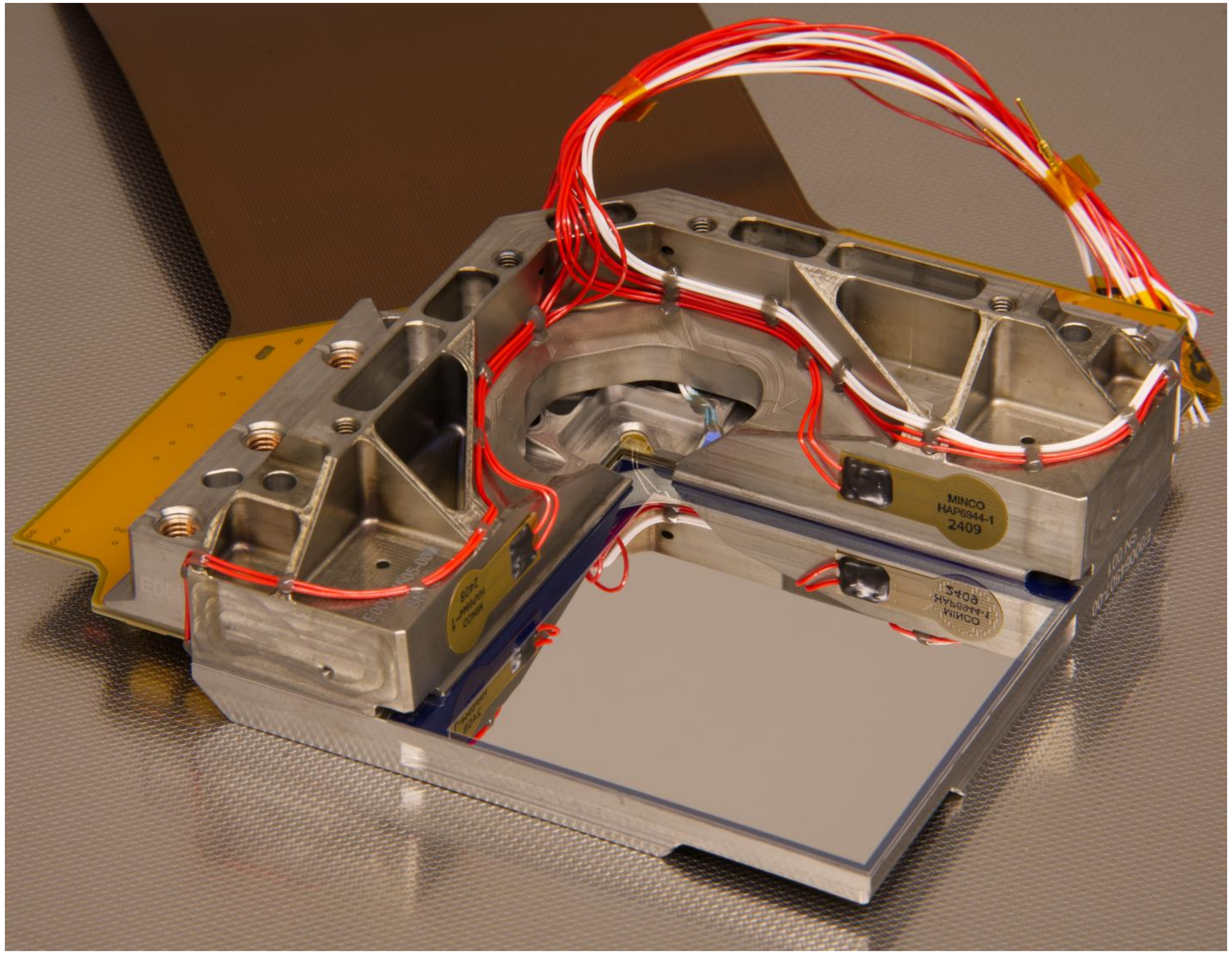


Material provided by V. Emberger

DEPFET Detector Modules (PXD 14)



Fast Detector



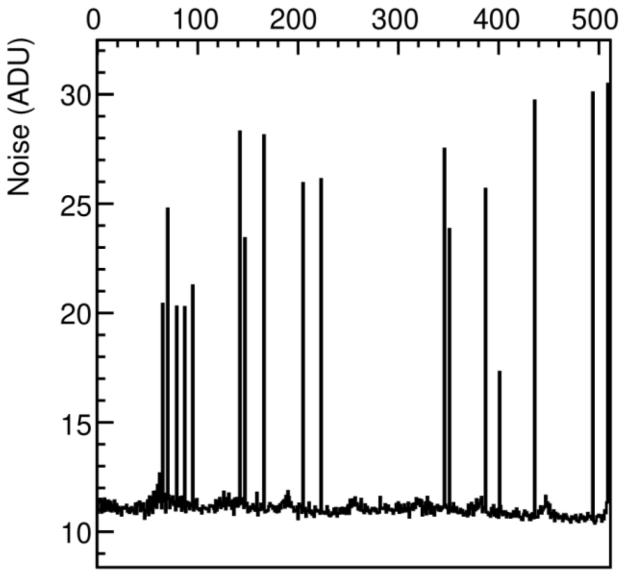
Large Detector

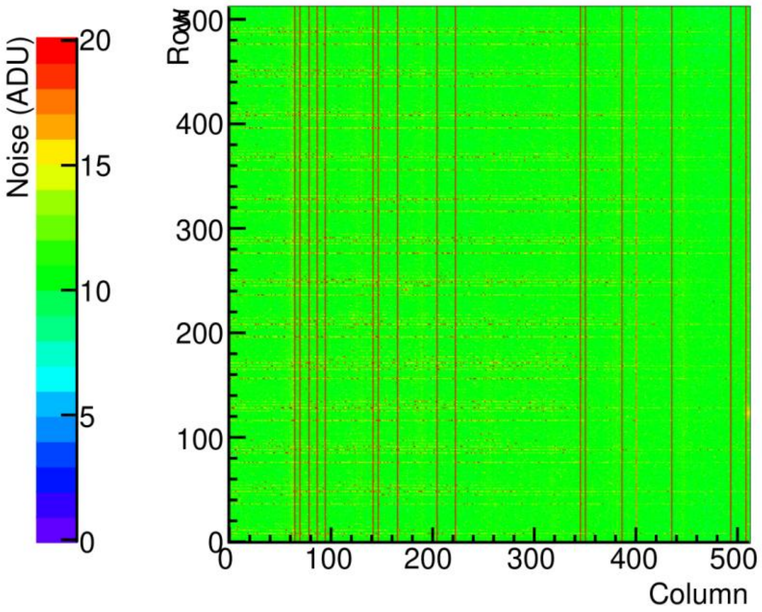
Noise Issue on Large Detectors (PXD 12)

Noisy columns

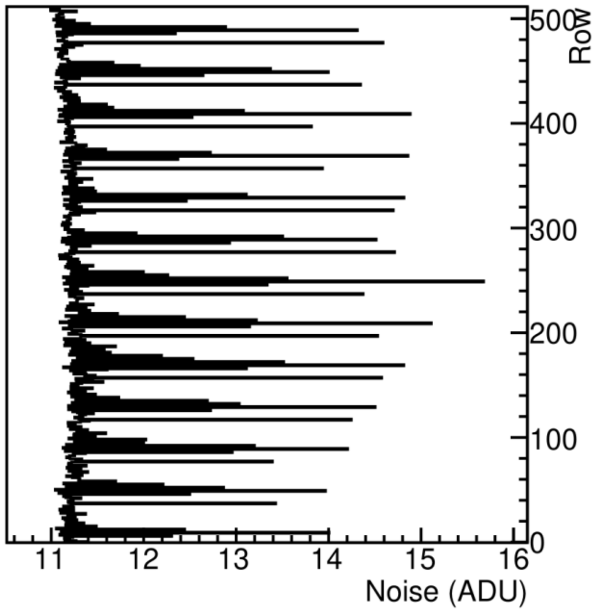
Randomly distributed

Different distribution for different sensors



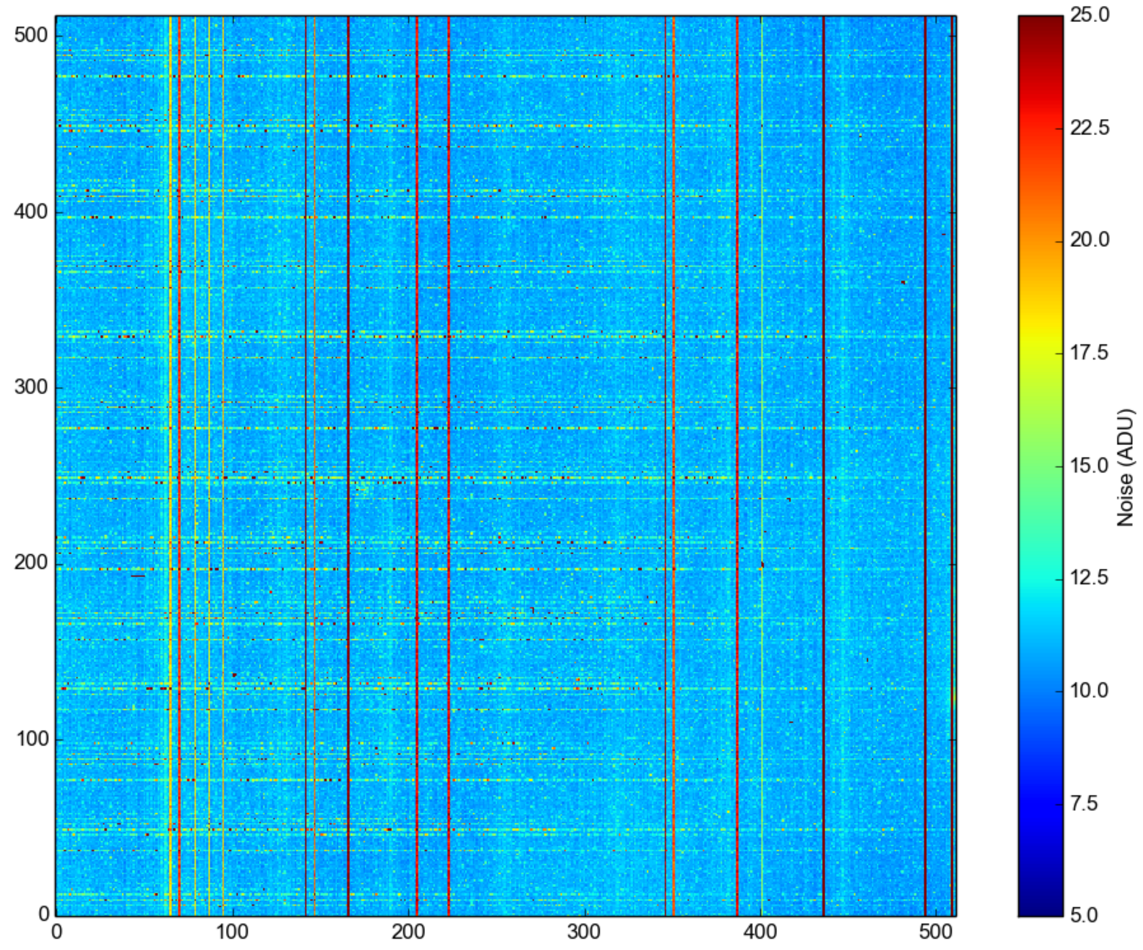


Row pattern with noisy pixels

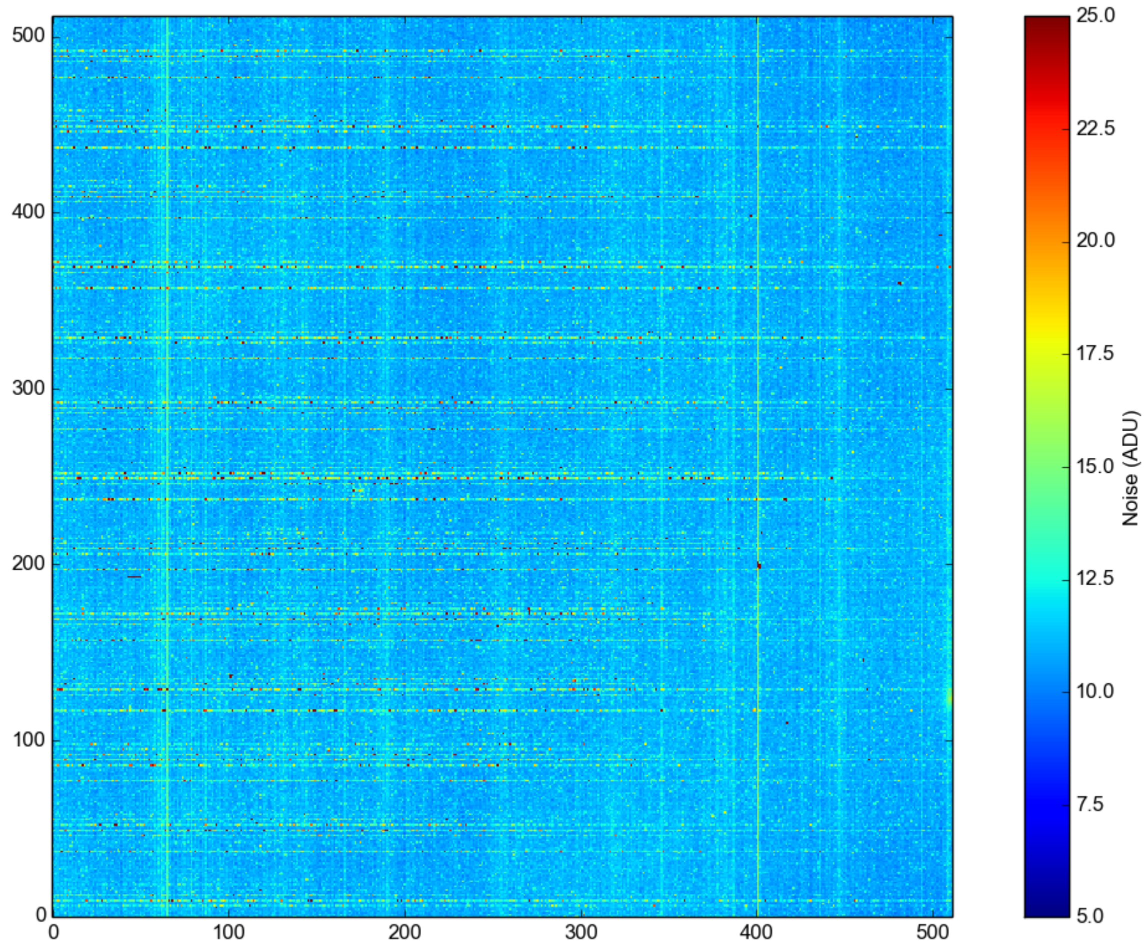


Same row pattern in all investigated sensors

Noise Issue on Large Detectors (PXD 12)

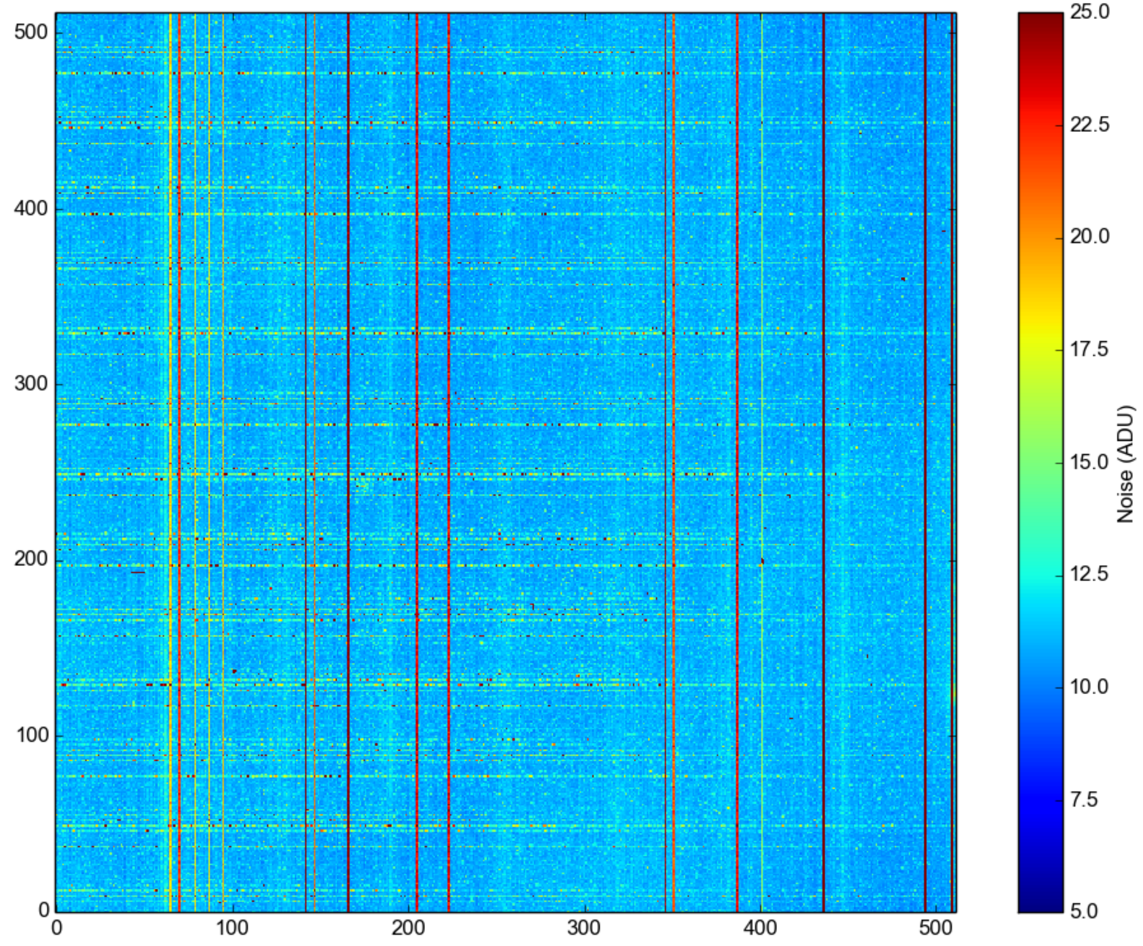


Pre-Flight Production – Second Batch (PXD 12-3)

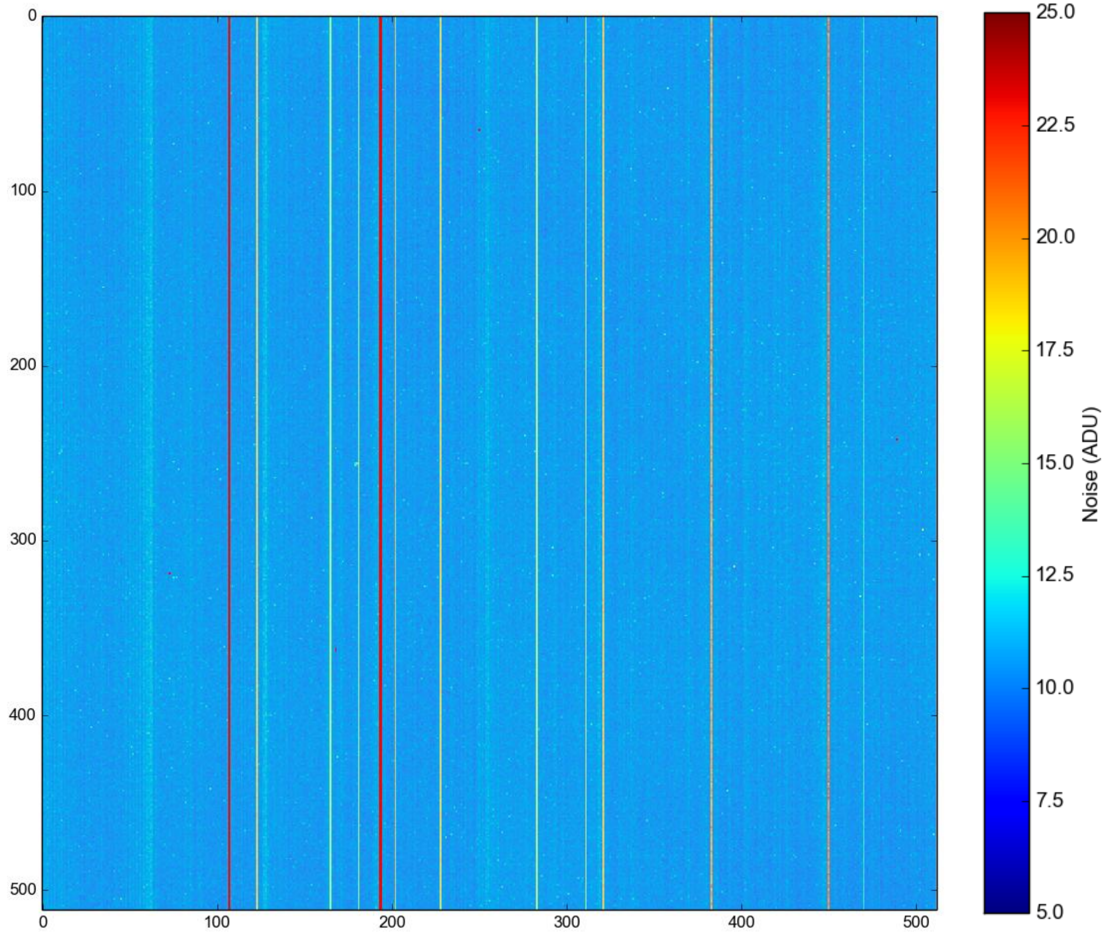


Second common mode correction on the noisy columns

Noise Issue on Large Detectors

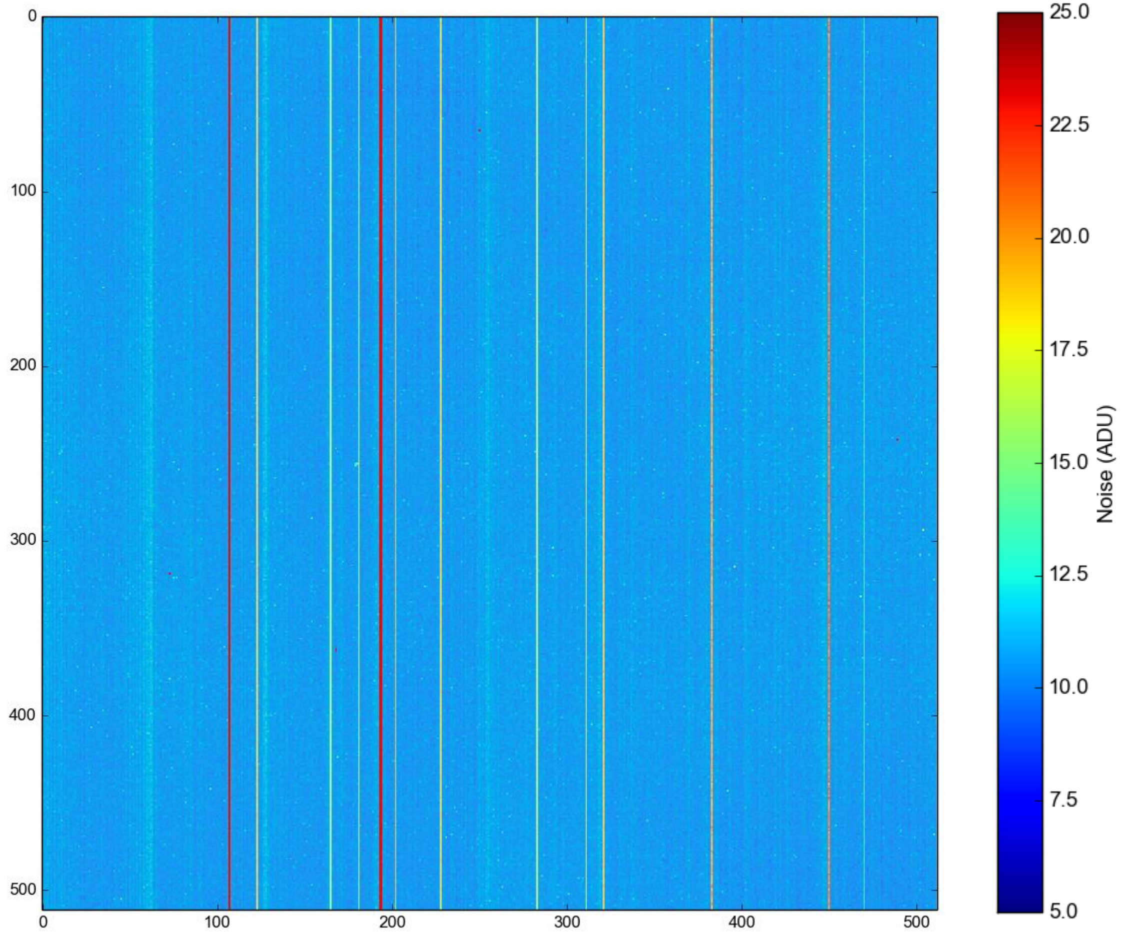


Pre-Flight Production – Second Batch (PXD 12-3)

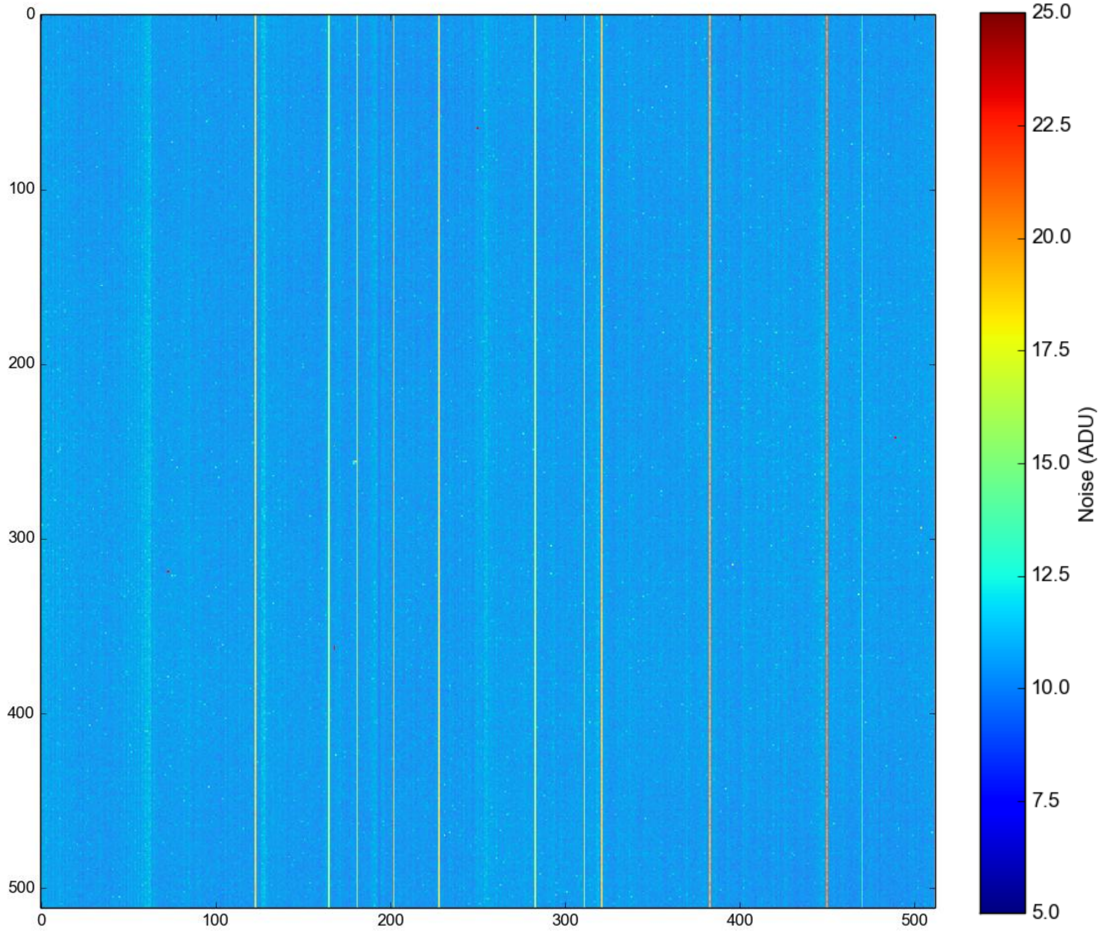


Flight Production – First Batch (PXD 14-6)

Noise Issue on Large Detectors (PXD 14)

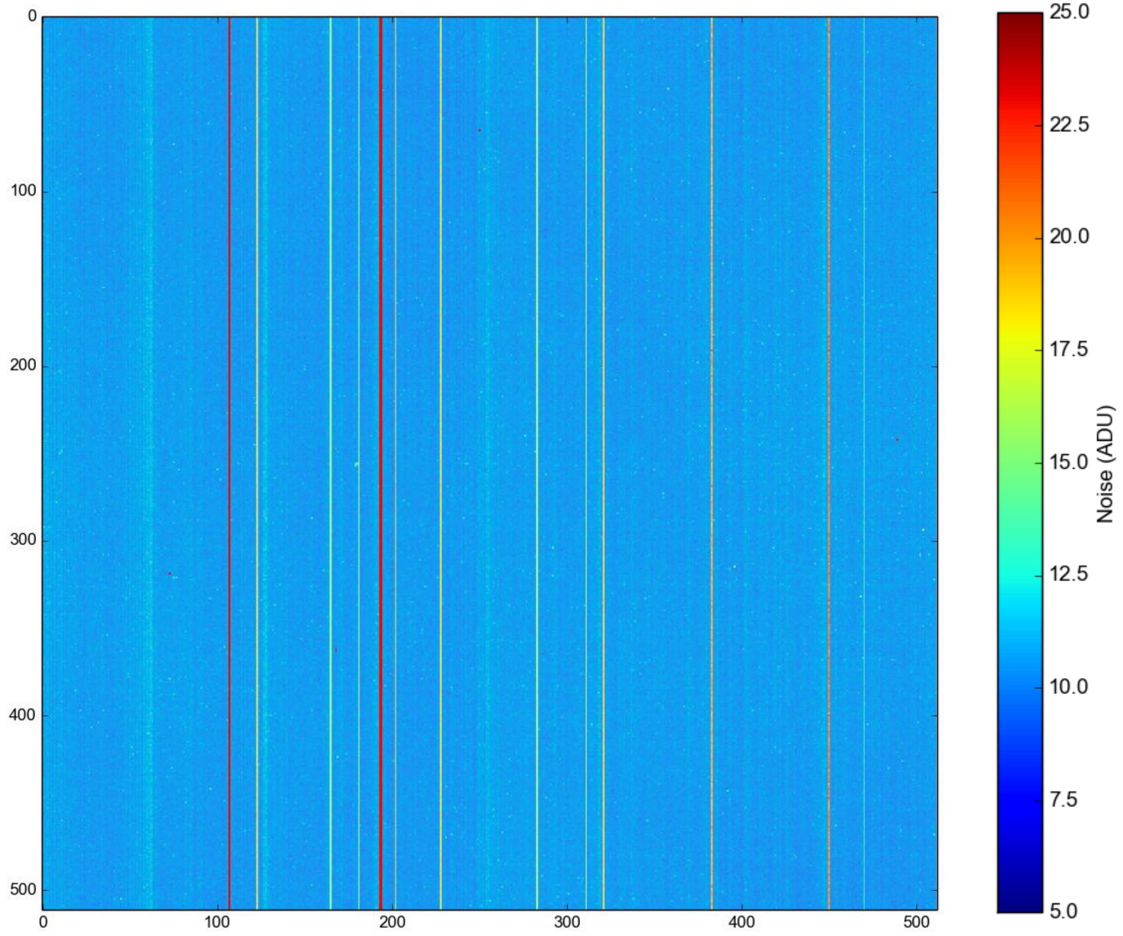


Flight Production – First Batch (PXD 14-6)

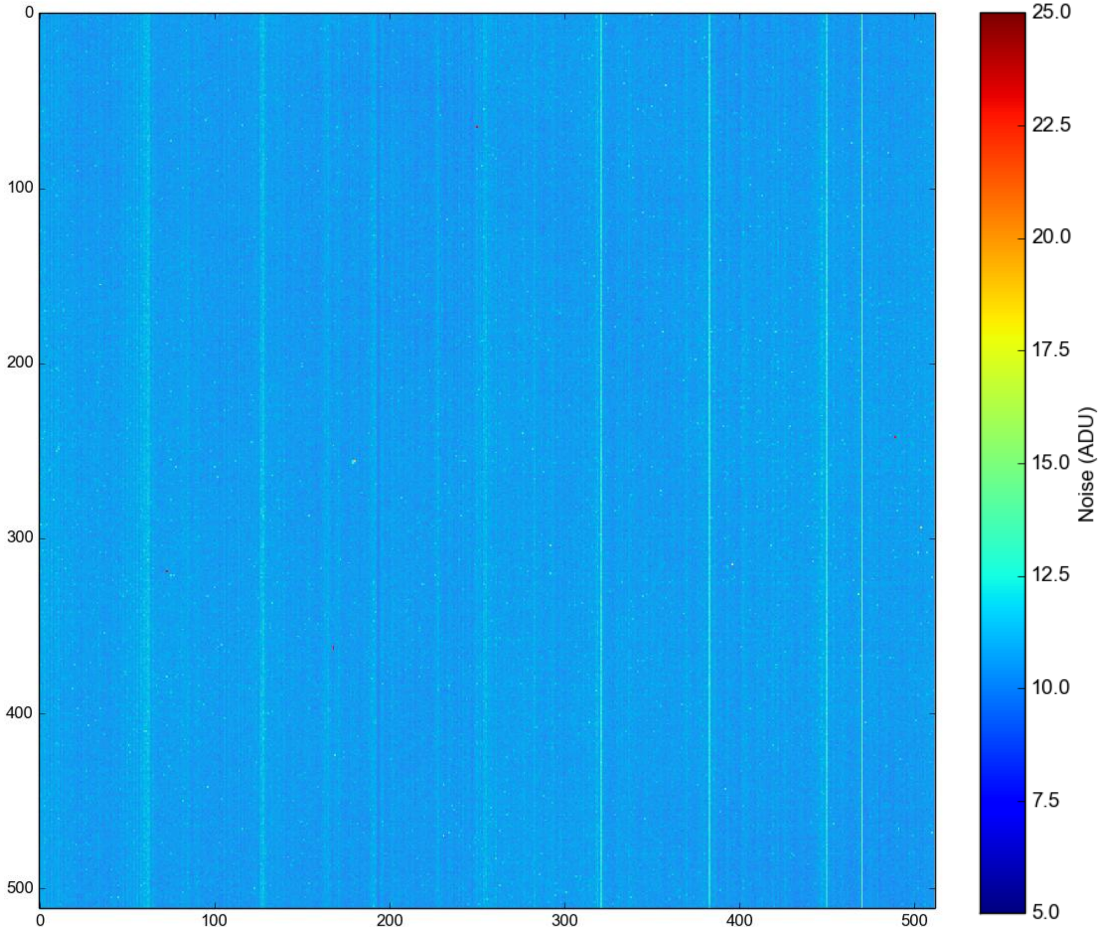


No Common Mode Correction on Dead Columns

Noise Issue on Large Detectors (PXD 14)



Flight Production – First Batch (PXD 14-6)



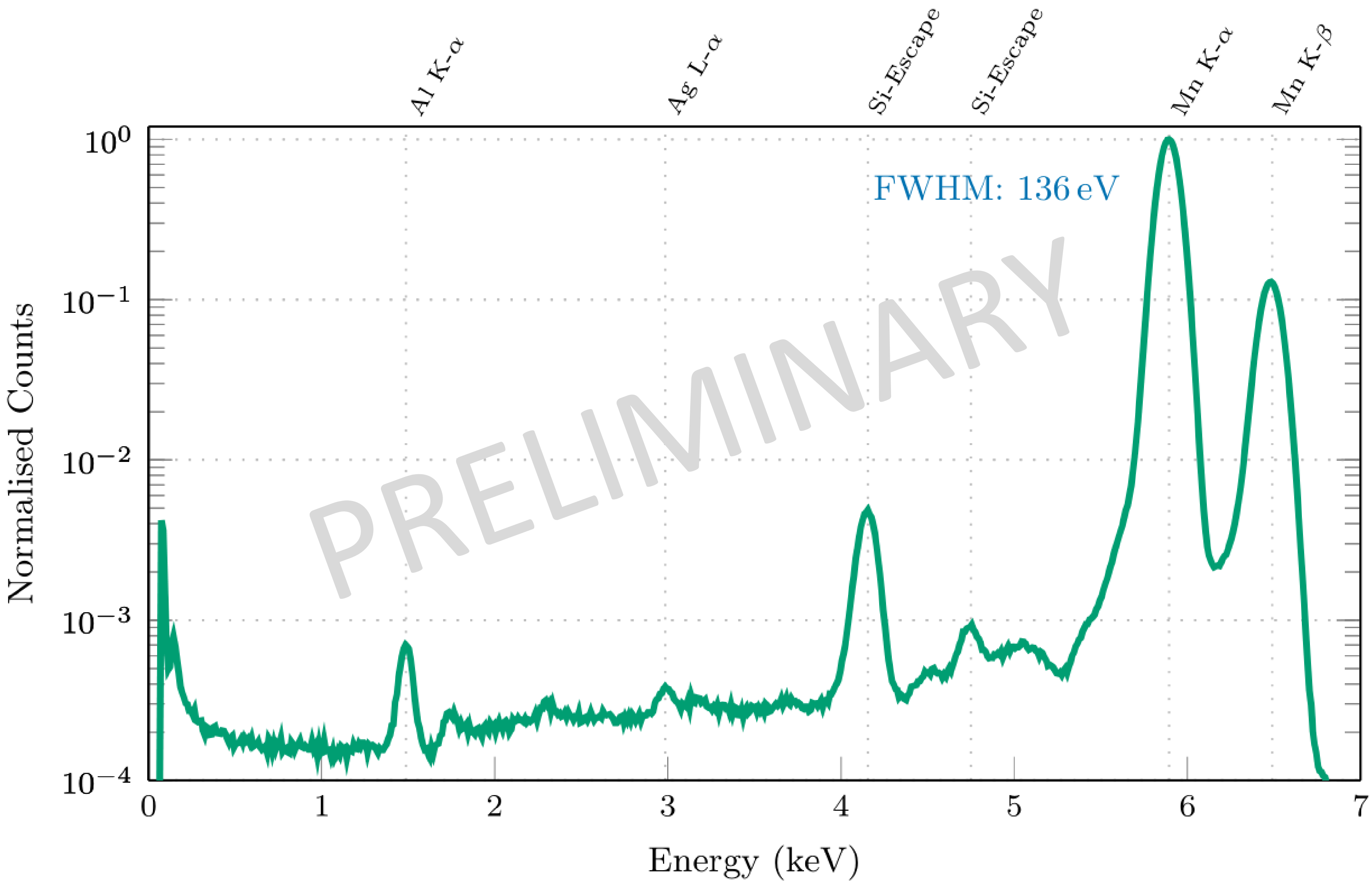
Second Common Mode Correction on Noisy Columns

Blinded Pixels (PXD 14)

No significant impact on the surrounding pixels!

More about this topic in the next talk by Peter Lechner.

DEPFET Detector Performance (PXD 14)



Large Detector

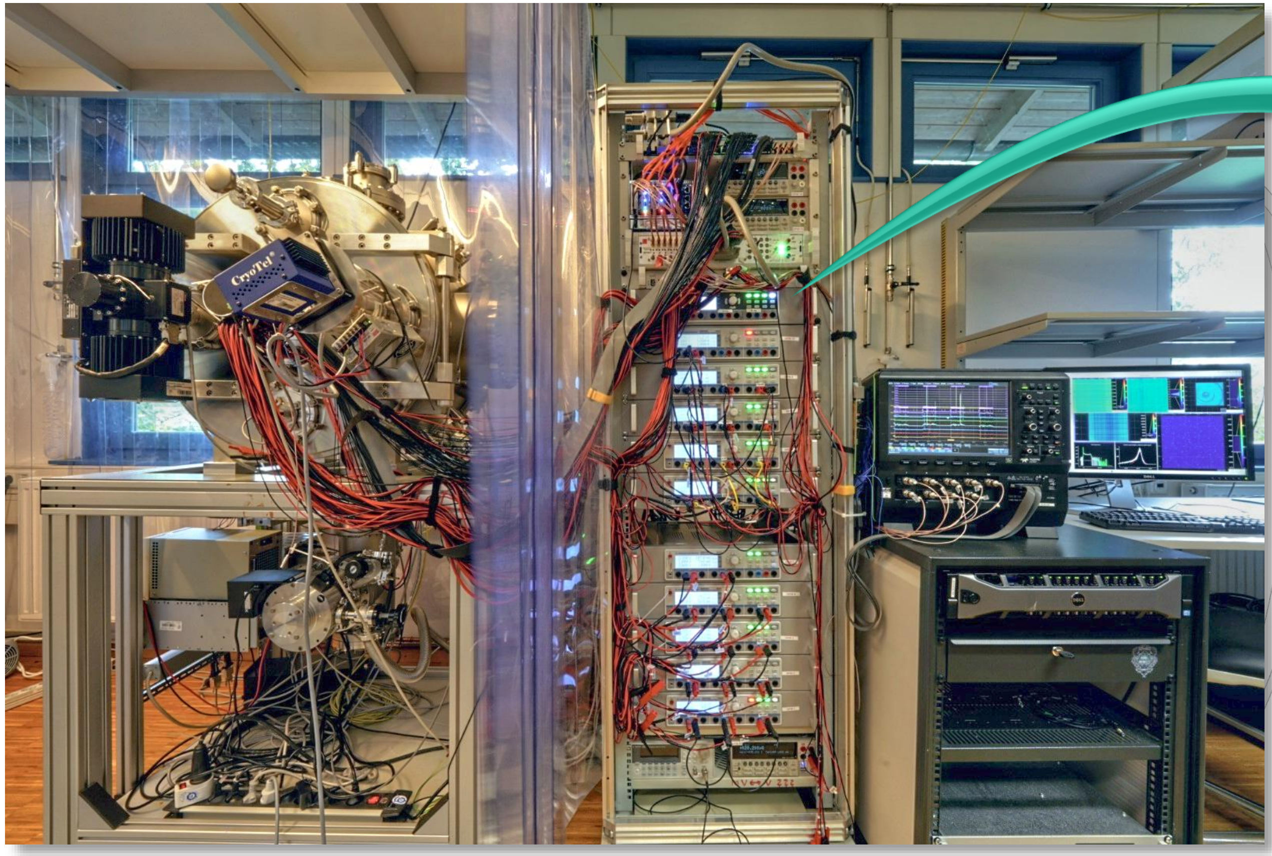
Flight Production

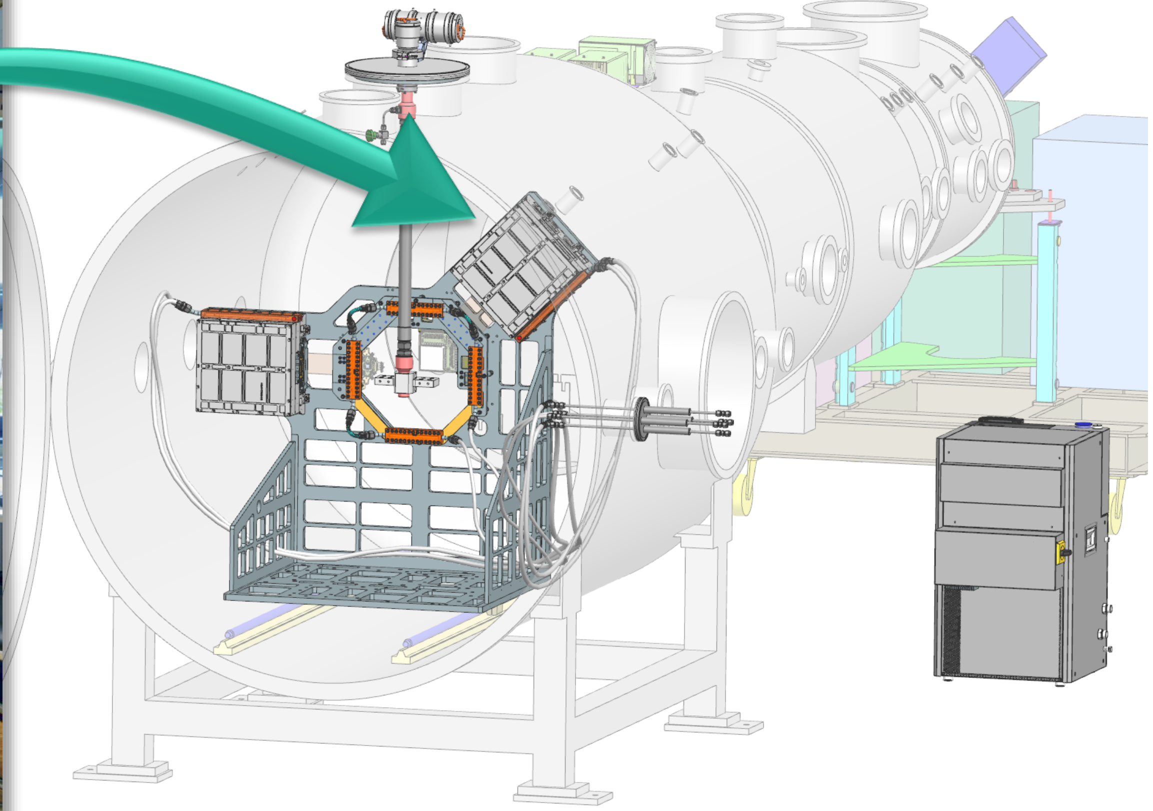
2.6 ms per frame

136 eV energy resolution at 5.9 keV

Signal Chain Tests in PUMA (MPE)

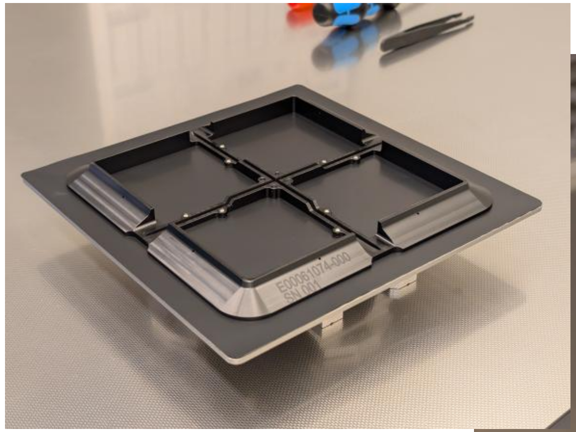
WFI laboratory setup

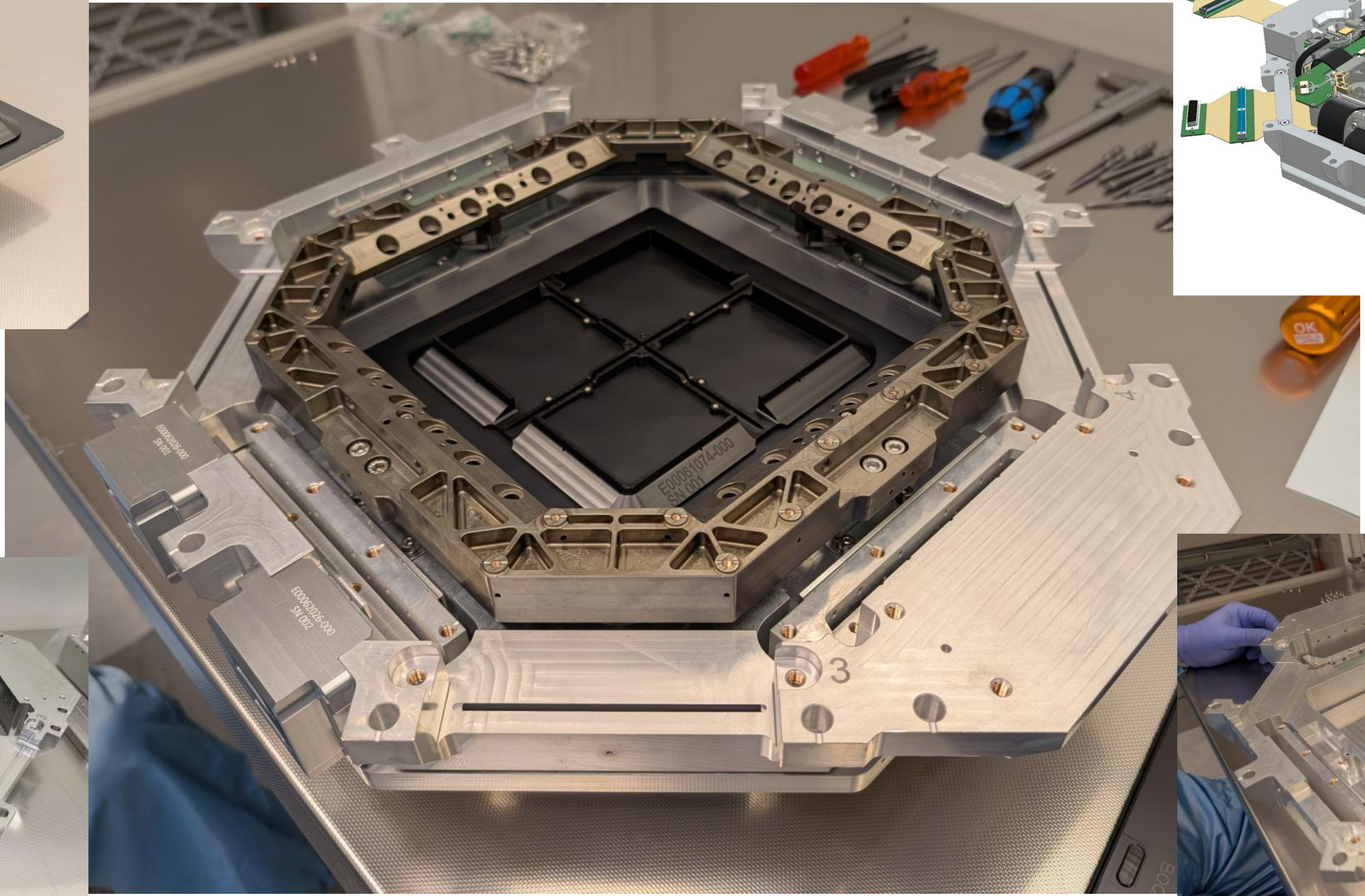


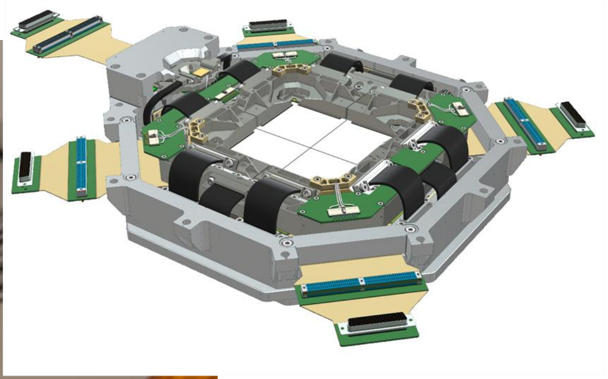


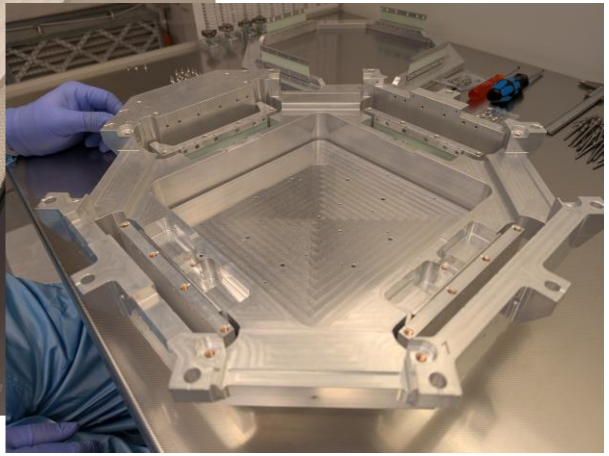
CAD by R. Strecker

Actual Hardware: Camera Head





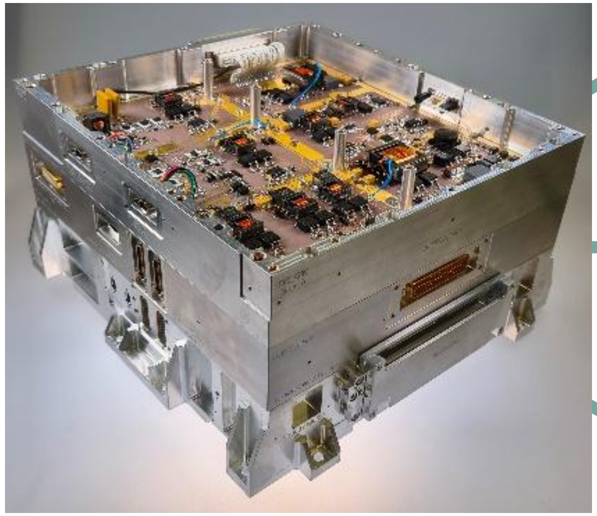


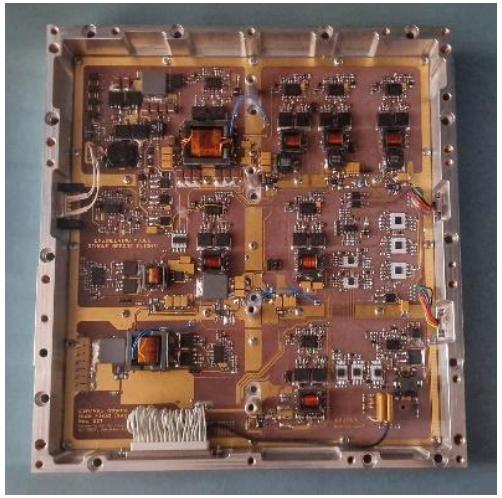


Material prepared by V. Antonelli, Images by D. Pietschner

Actual Hardware: Detector Electronics

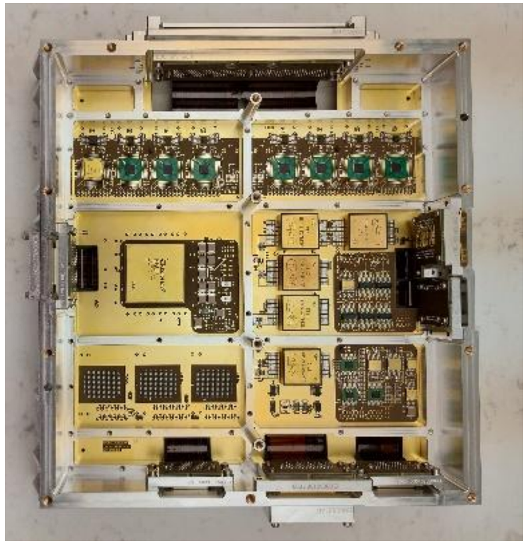
Detector Electronics Box





GIM

Astronomical Institute of the Czech Academy of Sciences



PCM

FPM

EBERHARD KARLS UNIVERSITÄT TÜBINGEN + MPE

Material prepared by V. Antonelli, Images by J. Reiffers

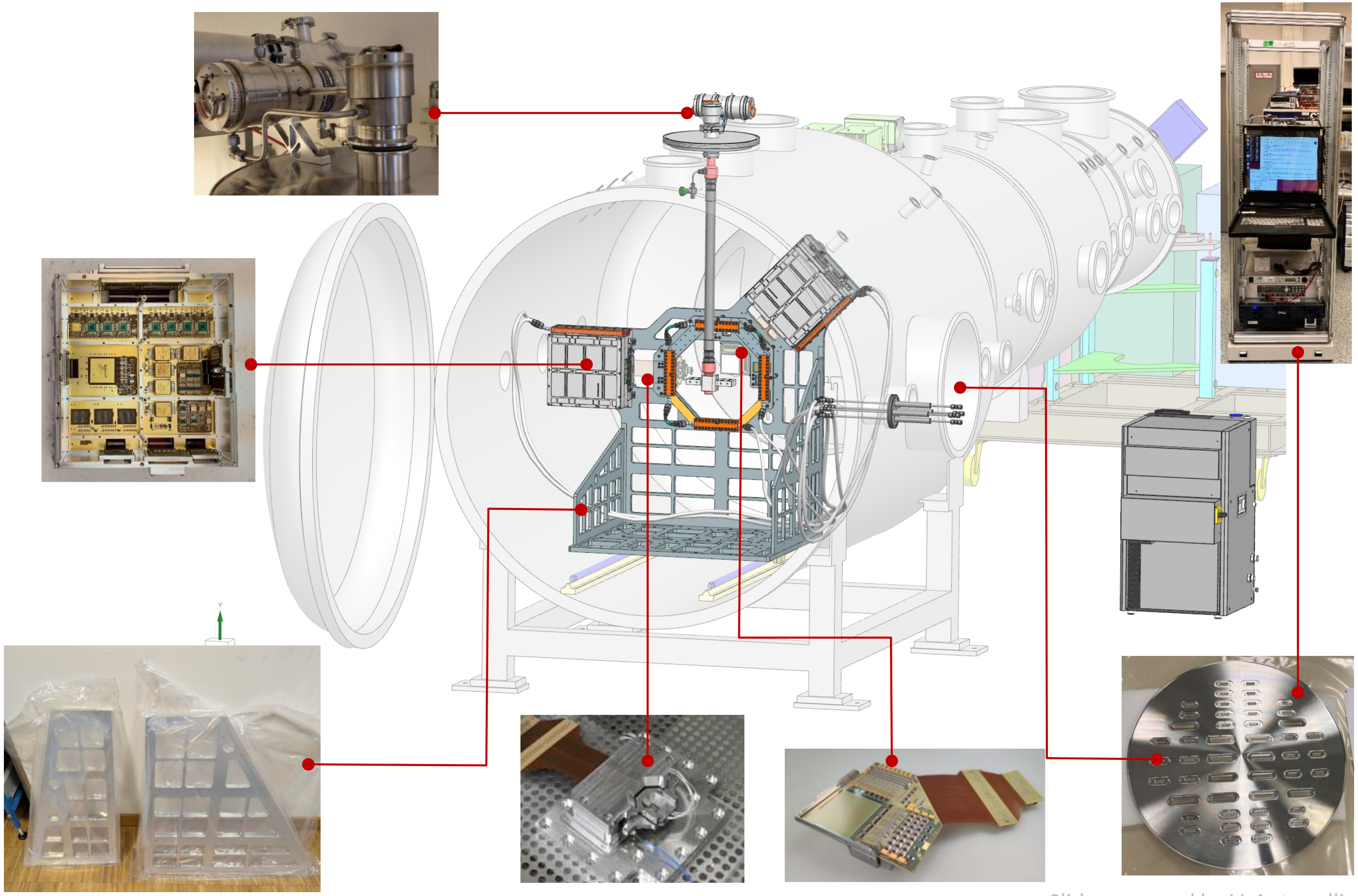
Assembly into PUMA

Scope:

- Verify the entire signal chain of CH and DE in the relevant environment
- Test different lengths and configurations of flex leads

Test set-up:

- Functional 1 FD + 1 LD
- 2 Functional DEs
- EGSE



Slide prepared by V. Antonelli

Thank you!