Silicon detectors for MeV gamma-ray astronomy

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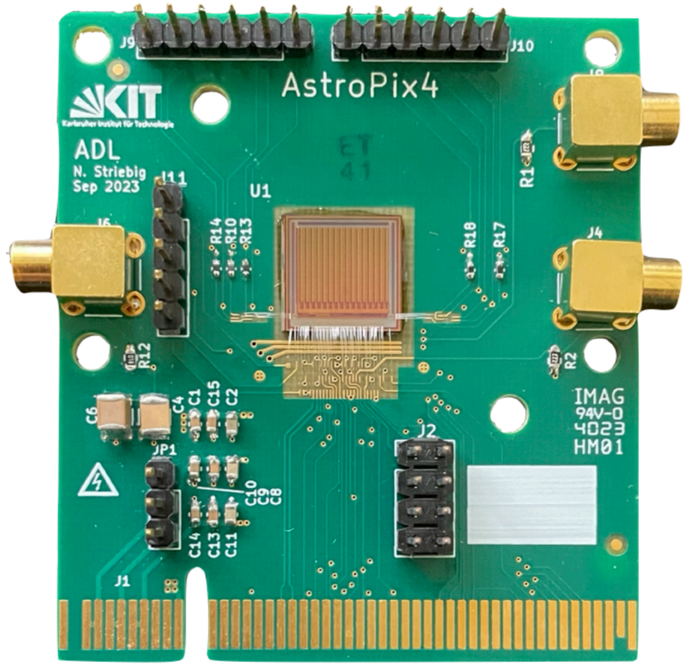
(with support from Simon, Ingrid, ….)



Discussion on silicon detector projects
DESY
June 12, 2025

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

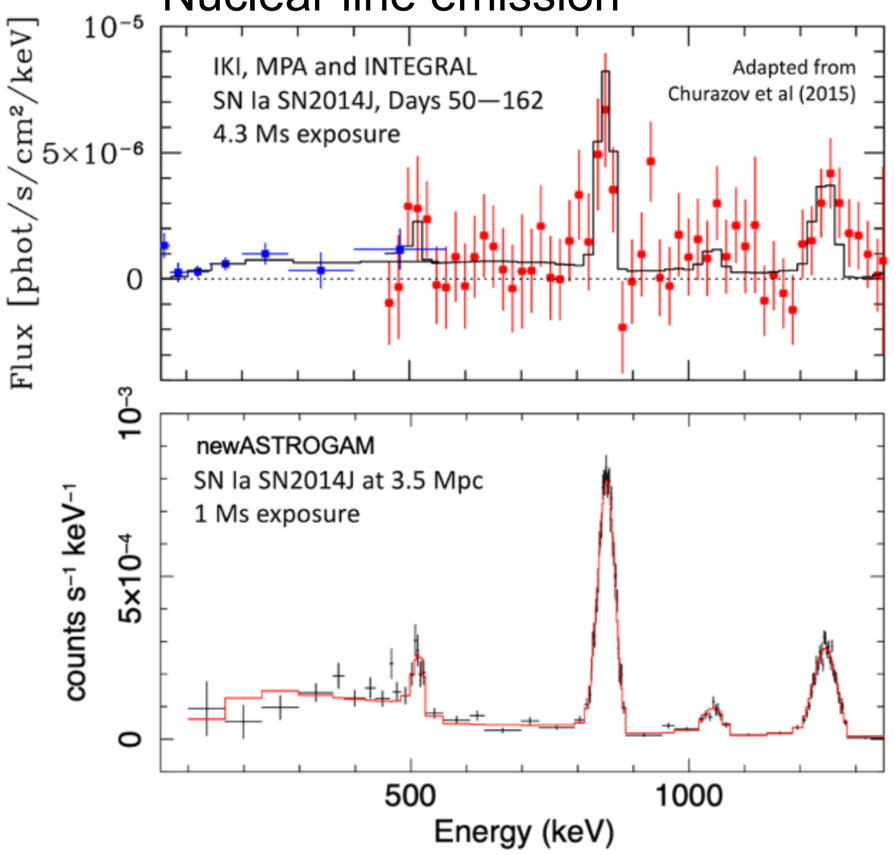
DESY

Gamma-ray astronomy

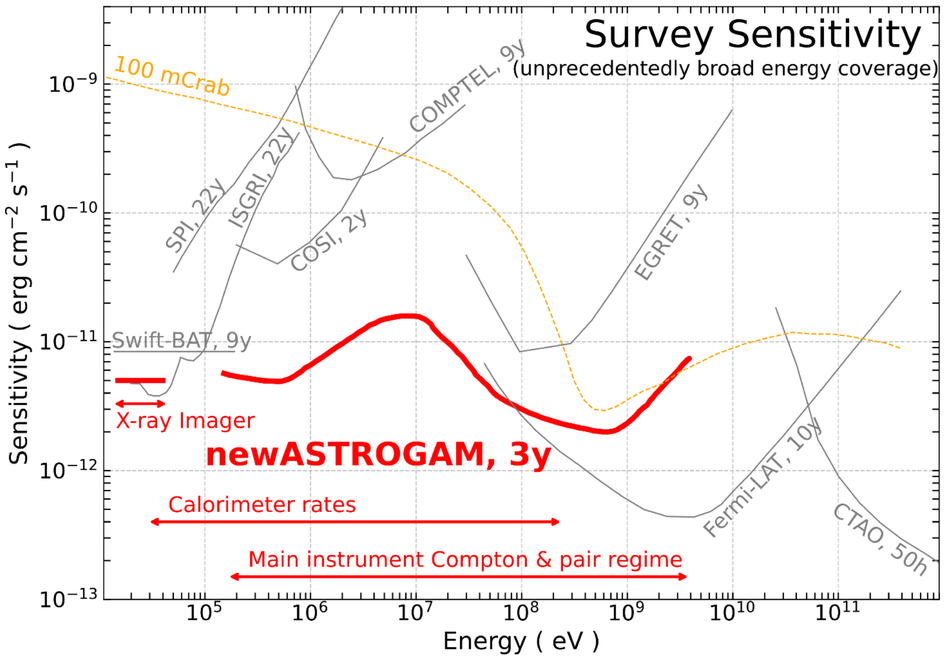
in the MeV energy band

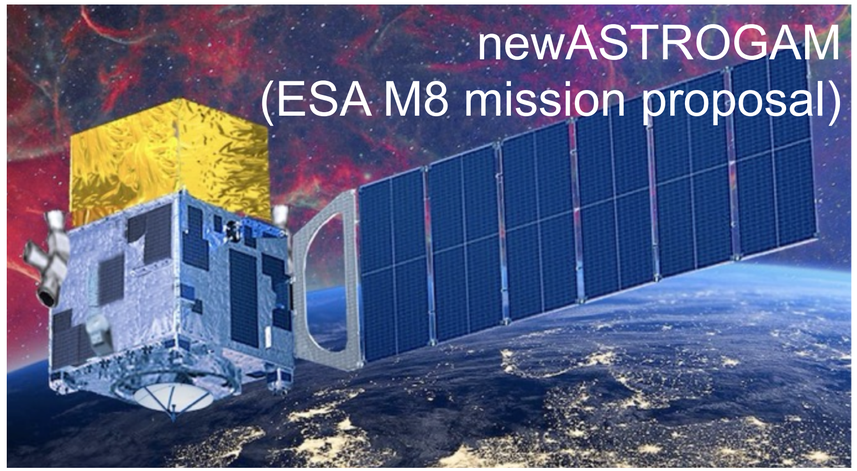
- The **MeV (100 keV — 100 MeV) energy band** is not covered with comparable sensitivity as the keV, GeV and TeV bands
- Broad range of **multi-wavelength / multi-messenger science** topics
- **Excellent match for DESY AP** focus on gamma-ray and multi-messenger astronomy
- **Excellent match for DESY's strength** in developing and building large-scale silicon detectors

Nuclear line emission



Non-thermal continuum radiation



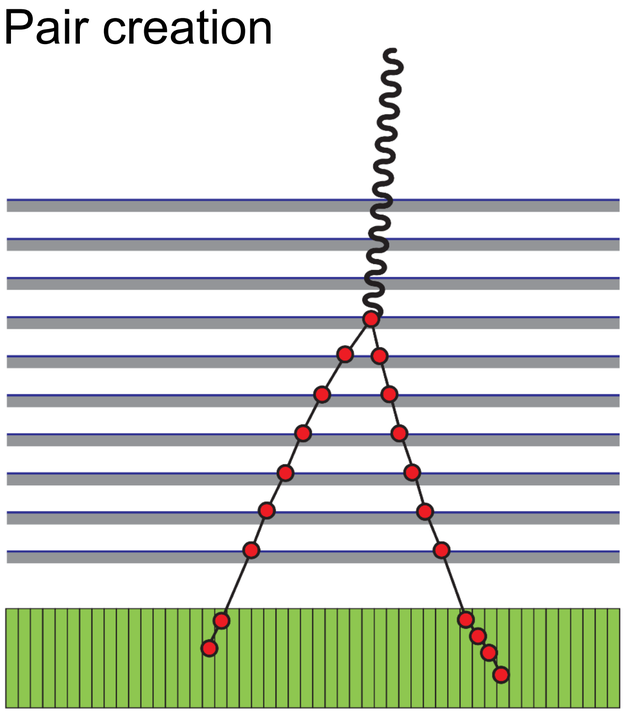


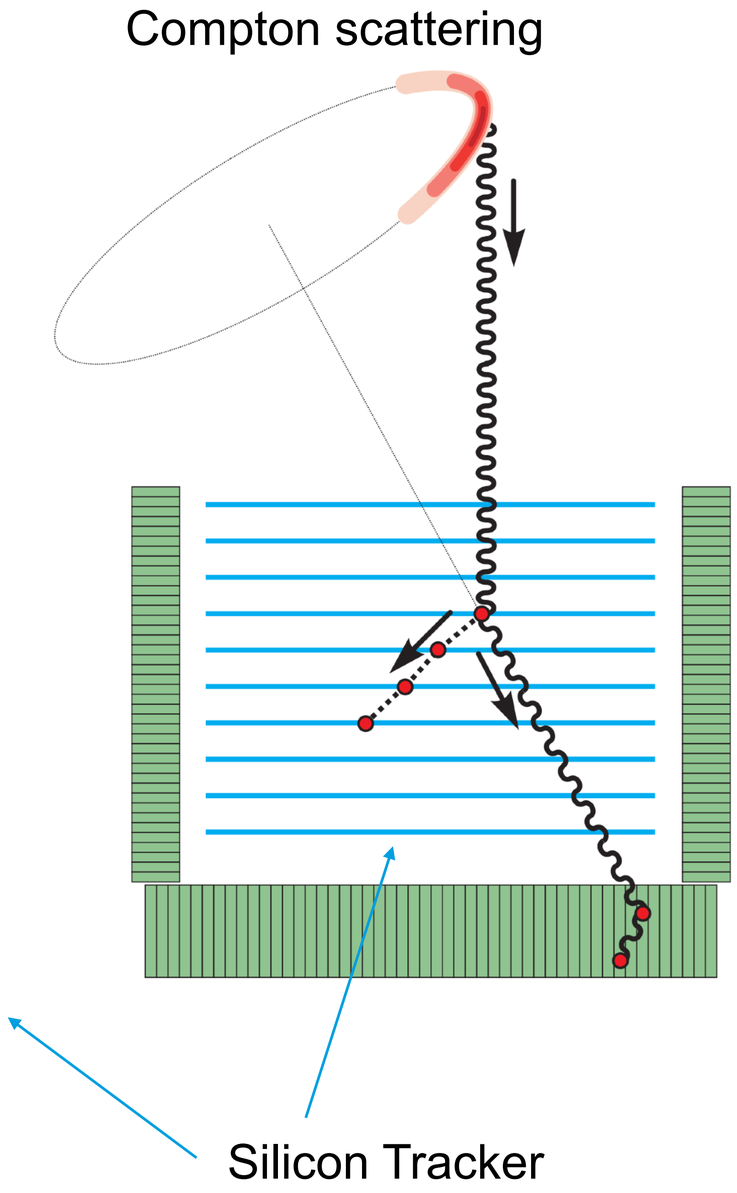
Needs instrumentation outside of Earth atmosphere

MeV gamma-ray detection

Compton and pair creation regimes

- **Common approach:** Si-Tracker + Calorimeter
- **Advantage:** suitable for Compton and pair creation regimes
  → 100 keV — few GeV energy coverage
- **newASTROGAM** proposal:
  - 2700 double-sided Si-strip detectors
    (75 layers, 36 DSSD per layer)
  - 9.5cm x 9.5cm detector area
  - 240µm/480µm strip pitch
  - 500µm thickness
  - 359,424 channels
  - ~350 W power budget





newASTROGAM

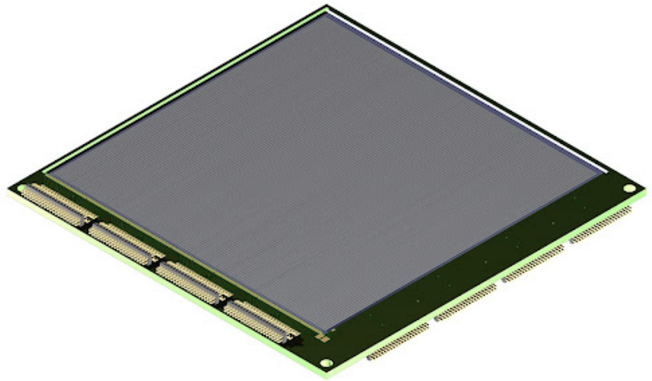
… a timeline (if newASTROGAM is selected in ESA M8 call)

- **Lead proposers:** Germany, Italy and France
  (plus contributions from DK, IE, PL, PT, ES, SE, and CH)
- **DESY focus** will be on **SI-tracker**
- Very positive reception by scientific council (plan to go through DESY CD0 phase)
- R&D (Phase 0/A) and construction efforts are funded by DLR (after selection by ESA)

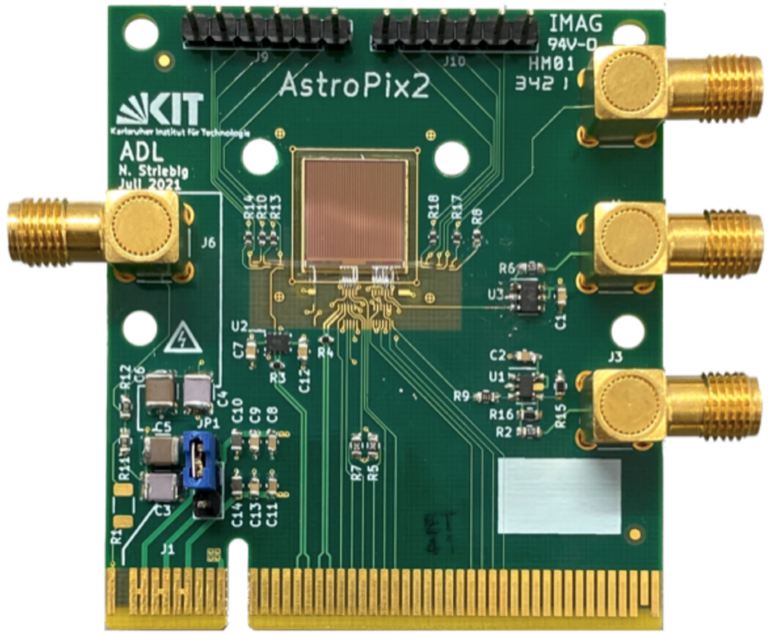
Timeline	Event	Notes
April 2026	Proposals due	
Q4 2026	Start of Study Phase 0	Up to 5 candidates
Q4 2027	Selection of Phase A candidates	Selection of up to 3 candidates
2026 - 2030	**Phase 0/A study**	**Develop final instrument design, few FTE effort**
Q2 2030	Mission selection	Selection of mission to be launched
2030 - 2032	**Phase B1**	**Ramp-up to production**
Q4 2032	Mission adoption	Full construction efforts after this date
2032 - 2041	**Payload integration & testing**	**Production / integration / testing of “flight model”**
>= 2041	Launch	

Silicon detector R&D

newASTROGAM phase 0/A or mission independent



- **Current baseline technology is DSSD** for Si-Tracker
  - For Compton regime xy-resolution in single detector mandatory
  - Strict power budgets for space missions favor lower channel count of strip detectors
  - But: challenging to manufacture & integrate (3x3 interconnected strip detector arrays)
    … in particular for the large number (25 m^2) of detectors needed



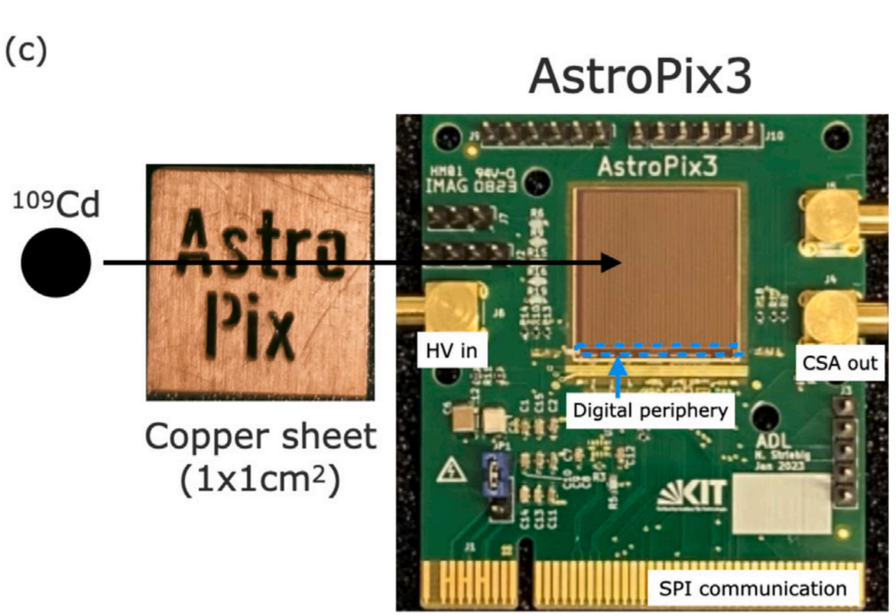
- **Low-power CMOS pixel detectors** are an emerging alternative
  - AstroPix developed by KIT (Group of I. Peric)
  - Currently investigated as tracker option for MeV gamma-ray telescope AMEGO-X (NASA proposal)
  - Current generation: AstroPix4
  - Mentioned as alternative to baseline DSSD-based tracker in newASTROGAM proposal

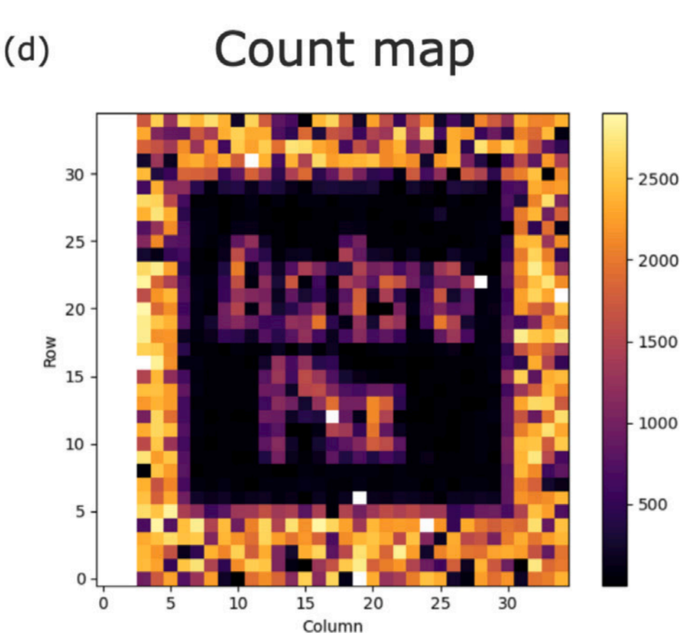
Requirements on pixel detectors

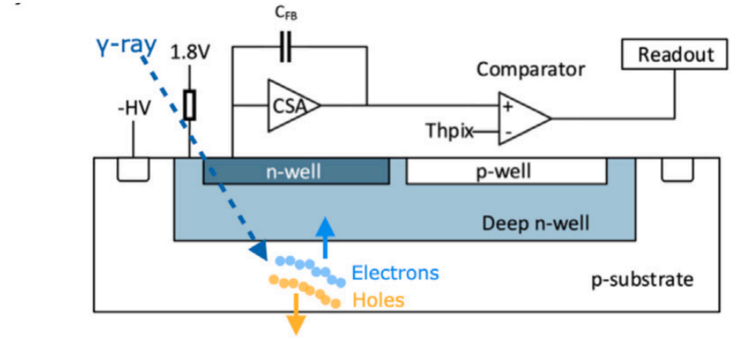
for space-based astronomy

- Core requirements:

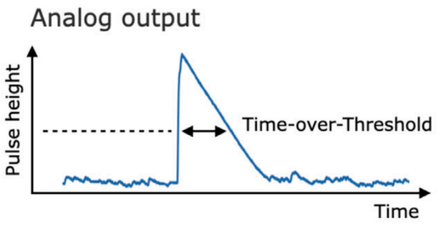
Power consumption	$<1.5\ \mathrm{mW/cm^2}$
Pixel pitch	$500 \times 500\ \mu\mathrm{m}^2$
Thickness	$500\ \mu\mathrm{m}$
Dynamic range	25 keV–700 keV
Energy resolution	<10% (FWHM) at 60 keV







Yusuke et al., NIMA, 2024



AstroPix3 performance

- **Energy resolution:** close to 10% goal
- **Dynamic range:** up to 200 keV (700 keV goal)
- **Depletion depth:** relatively low (on tested 300 Ω cm substrate)
- **Power consumption:** 4.1 mW/cm² (~ factor 3 higher than required)
- Several successful tests of radiation hardness

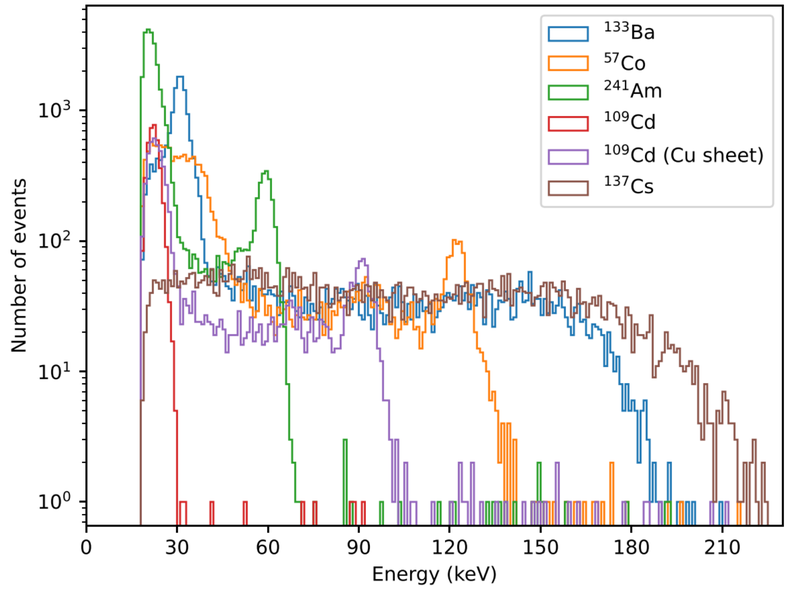
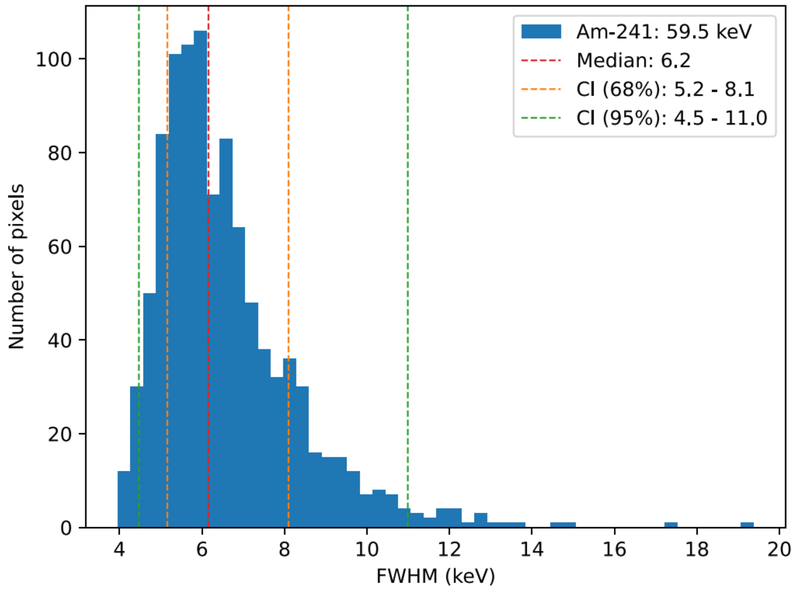
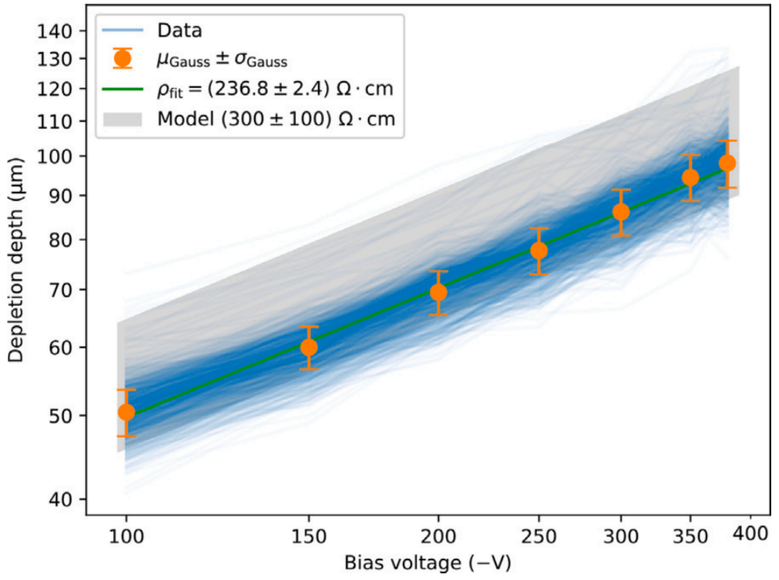


Fig. 12. Energy spectra obtained from a single pixel of AstroPix3.

Yusuke et al., NIMA, 2024





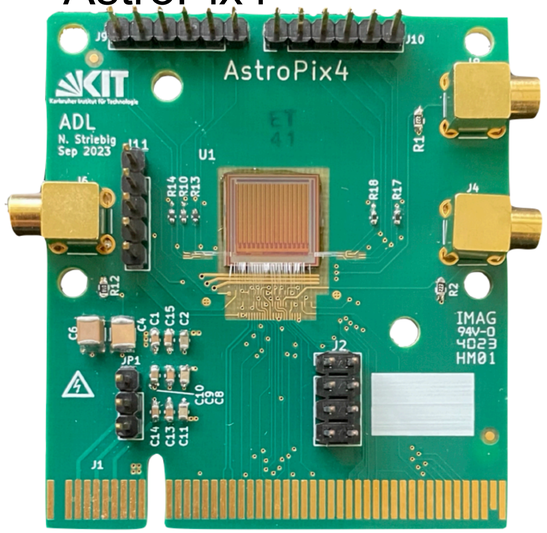
AstroPix

Current status and expectations

- **AstroPix_v4** (1x1cm) produced and undergoing testing, **AstroPix_v5** (2x2cm) in development:
  - Re-designed digital part: 3mW/cm^2 → 0.7mW/cm^2 (+ 1 mW/cm^2 for analog part)
  - Increased energy range to 700 keV
  - Full depletion expected on substrates with > 10 kΩ cm2 resistivity

- NASA plans to test three AstroPix3 quad modules on a sounding rocket

AstroPix4

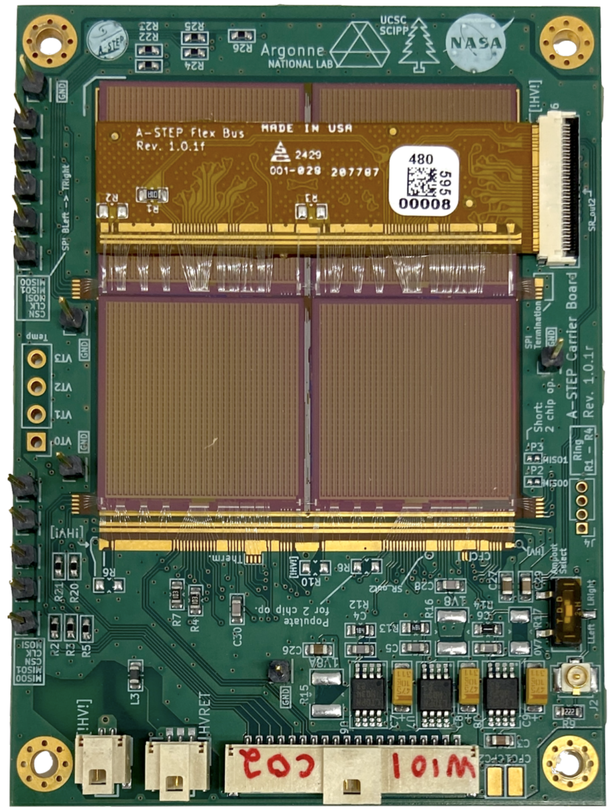


AstroPix3 power consumption (4 cm^2)

	Analog		Digital
	VDDA	VSSA	VDDD
Nom. Voltage	1.80 V	1.20 V	1.80 V
Current	1.47 mA	1.33 mA	6.88 mA
Power	2.65 mW	1.60 mW	12.24 mW

Striebig et al., JInst, 2024

Steinhebel et al., arXiv:2501.11698



AstroPix3 quad module

Plans for future Si detector activities in AP

- **R&D (independent of outcome of ESA call):**
  - Investigate the potential of AstroPix for newASTROGAM / future ESA gamma-ray mission
  - Continued development of AstroPix with KIT as partner
  - Detector integration / assembly / front-end electronics towards potential flight tests

- **In case of a successful newASTROGAM proposal:**
  - Take a lead role in tracker development and construction
  - Phase0/A: evaluate AstroPix as an alternative for DSSD baseline design, prototype tracker modules and front-end electronics (DSSD / AstroPix)
  - Mission adoption: newASTROGAM tracker construction / integration / testing (Germany/Italy)