Progress on X-ray Imagers at MIT

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At MKI:

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At MIT Lincoln Laboratory:

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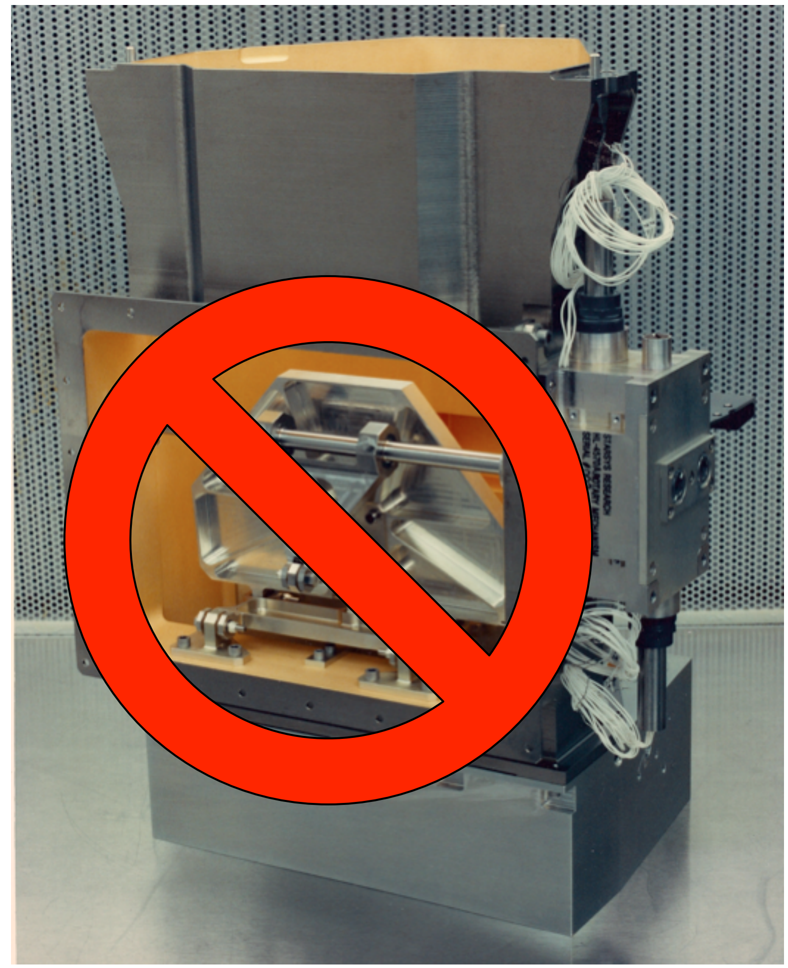
Overview

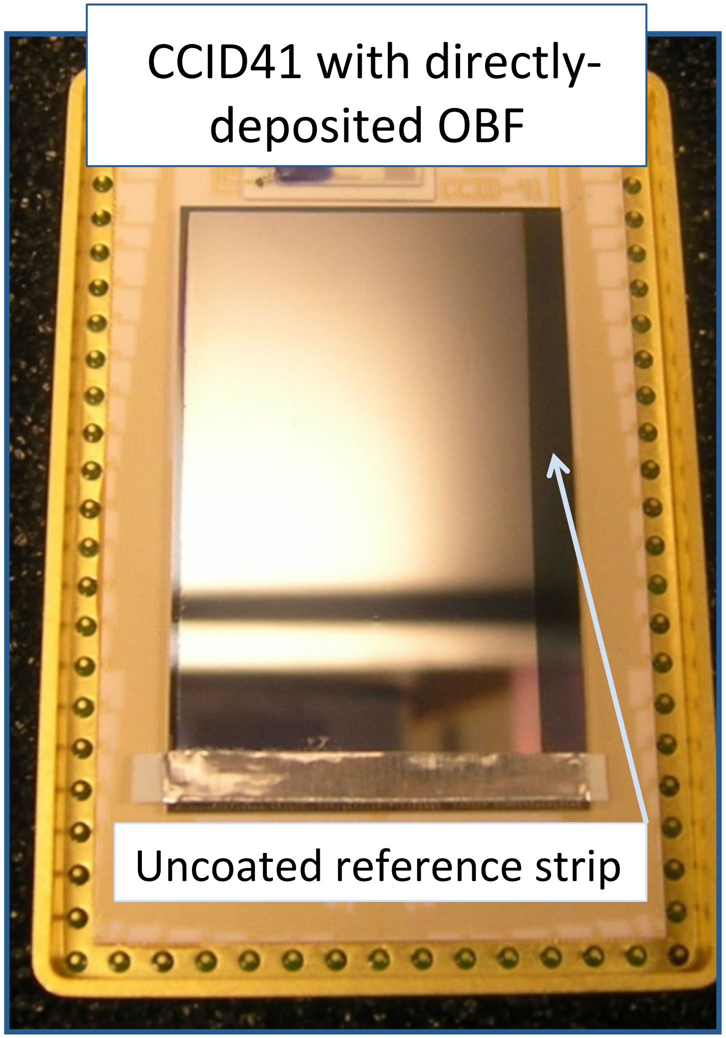
- Near term: Directly-deposited blocking filters
- Far term: 3-D Active Pixel X-ray Sensors
- Mid term: Advanced CCDs

Deposited Filters: Objectives

- Avoid fragile optical/ UV blocking filters, associated support hardware (e.g vacuum doors), risk & I&T expense.
- Improve instrument performance



Status: 1st Coated BI CCD under test



- Chip-level coating process characterized in depth
- 1st test device: engineering grade with prior MBE BI treatment
- OBF: 220nm Al over 140nm 'buffer' layer
  - Buffer reduces OBF-induced dark current
- Characterization in progress
  - Soft X-ray QE confirms Al thickness
- Next:
  - Thinner buffer layer on higher-quality device

Beyond CCDs: Active Pixel Sensors (APS)

- Faster readout → better QE, count-rate, timing
  - * Speed comes from parallelism & technology
  - * Parallelism comes from CMOS compatibility
- "No" charge transfer → better radiation tolerance
- Integrated signal/data processing
  - * Allows Gpix focal planes at kHz rates
  - * Allows for on-chip intelligence (e.g., event detection)

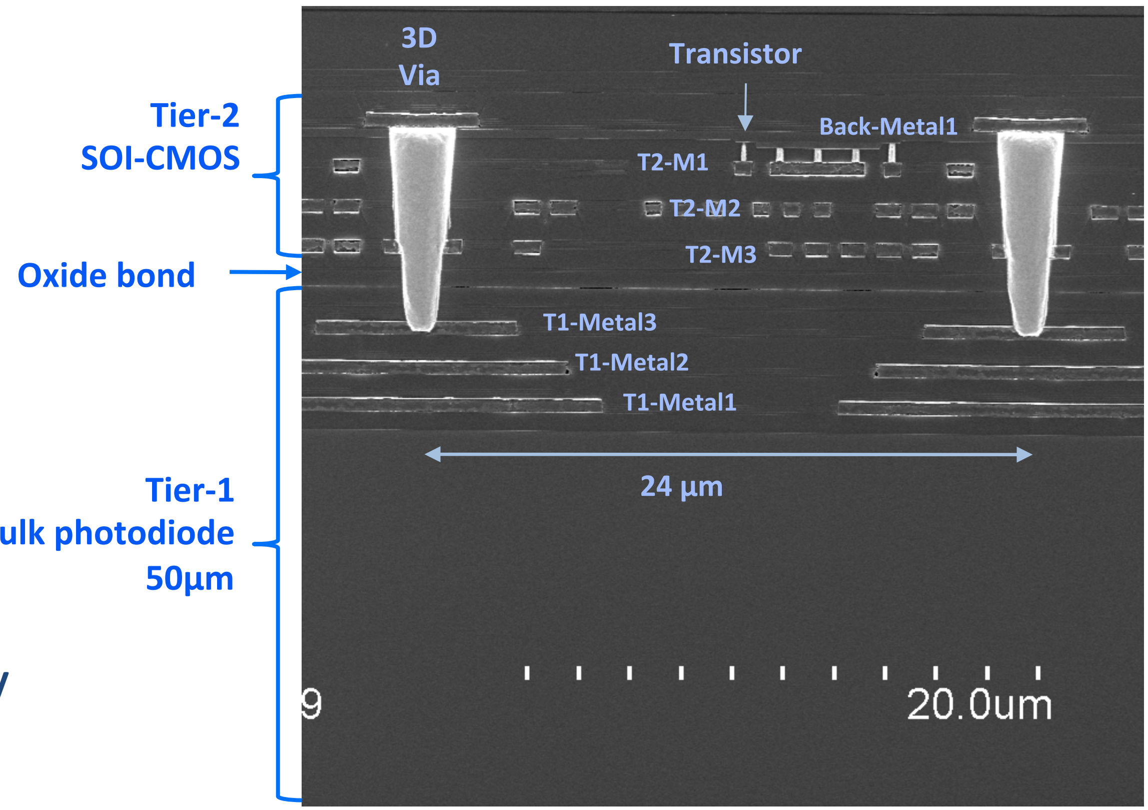
Challenges for APS in X-ray Astronomy

- Challenge for monolithic architectures: detection efficiency
  - * Difficult to deplete ~100+ μm
  - * May be difficult to tile large focal planes
- Challenge for hybrid architectures: noise
  - * Interlayer connection has large capacitance → lower responsivity, higher noise (referred to input)
- Challenge for both: demonstrate proper BI treatment

MIT/Lincoln 3D X-ray Sensor (APS2)

Readout ‘tier’:
* FDSOI CMOS
* 350nm/3.3V

Inter-wafer connection:
* Tungsten Via
* Low-T oxide bond



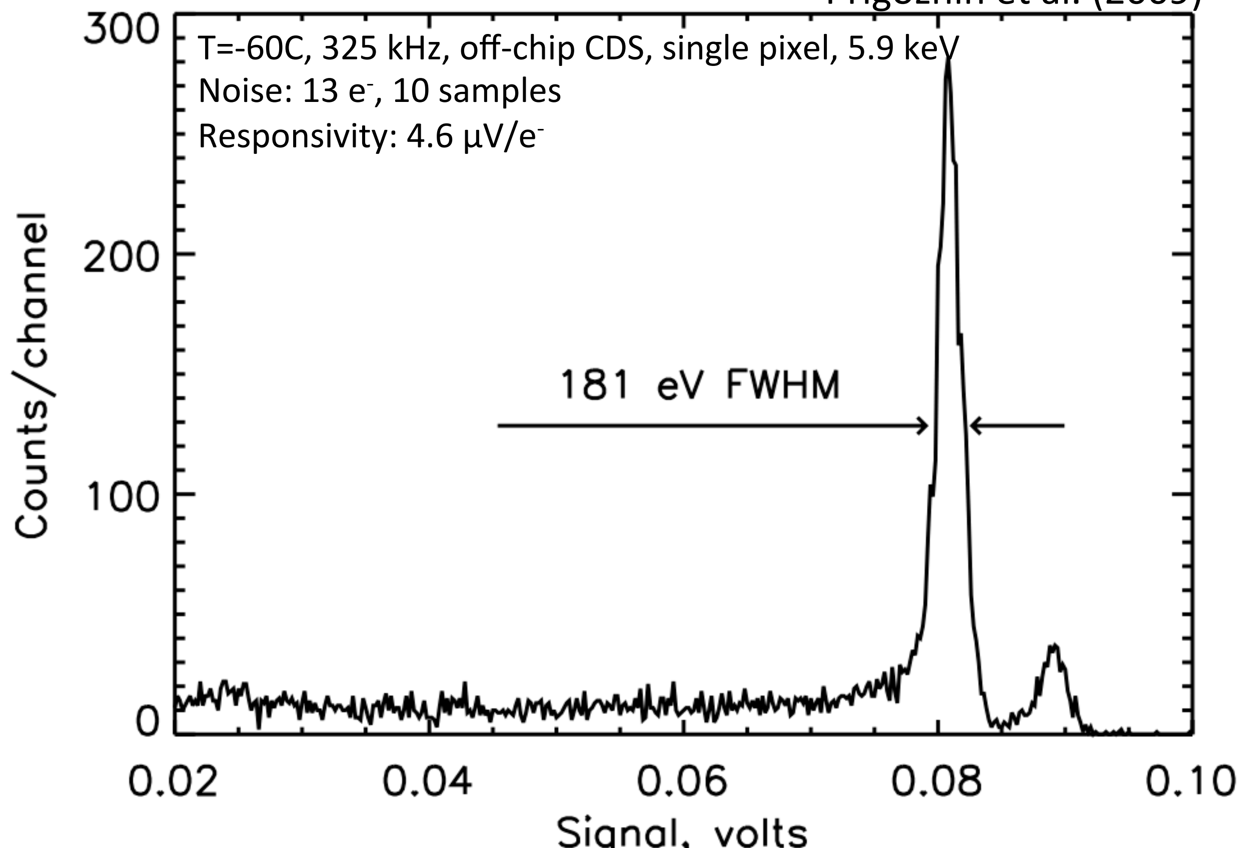
Detector ‘tier’:
* Bulk photodiode array
* 3 kΩ-cm n-substrate
* Thinned (50 mm)
* Back-illuminated

Test Array: V. Suntharalingam, MIT/LL
* 256 x 256, 24 µm pixels

X-ray Performance at 5.9 keV

MIT/LL 3-D X-ray Active Pixel Sensor APS2

Prigozhin et al. (2009)



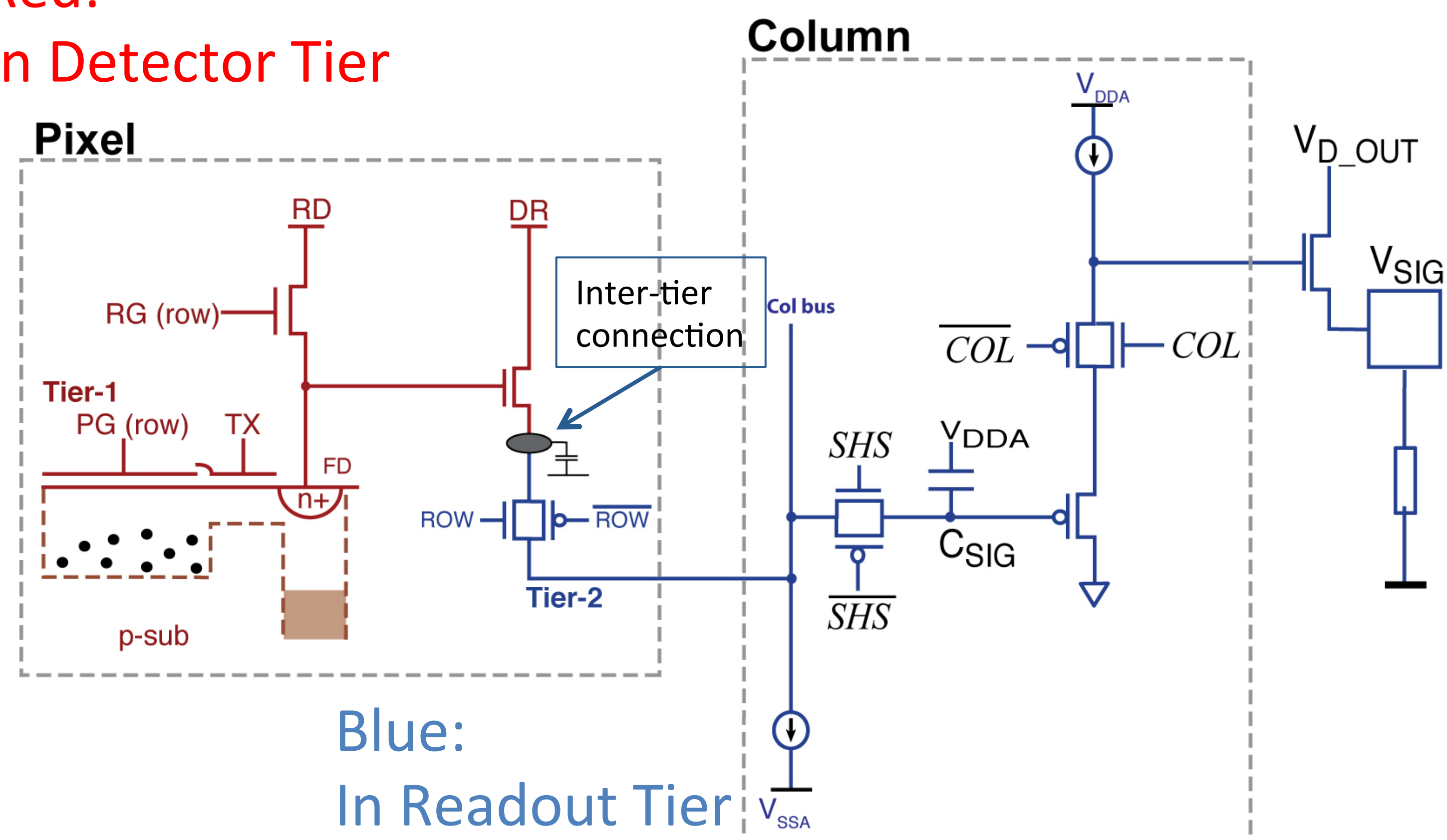
Next Generation Sensor APS3

Goals:

* Reduce noise through improved responsivity, lower transistor noise
* Reduce inter-pixel coupling through better layout
* Demonstrate high-quality back-illumination (good soft X-ray response)

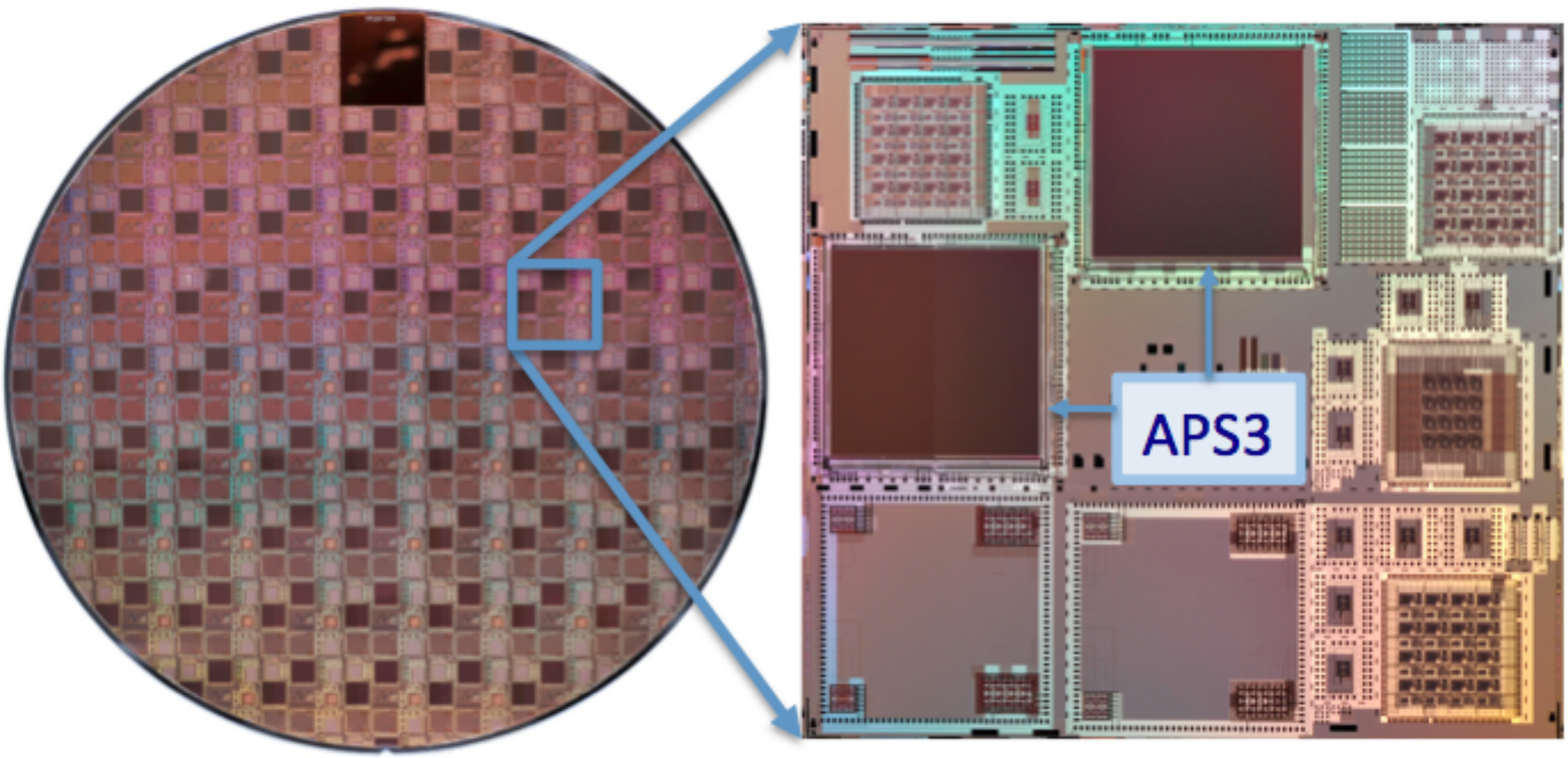
APS3 pixel with CCD-like output

Red:
In Detector Tier



Blue:
In Readout Tier

APS3 CMOS Readout Tier



200mm-diameter wafer (45 die)

Shared, 22 mm die; 2 APS3 readouts

APS3 Status

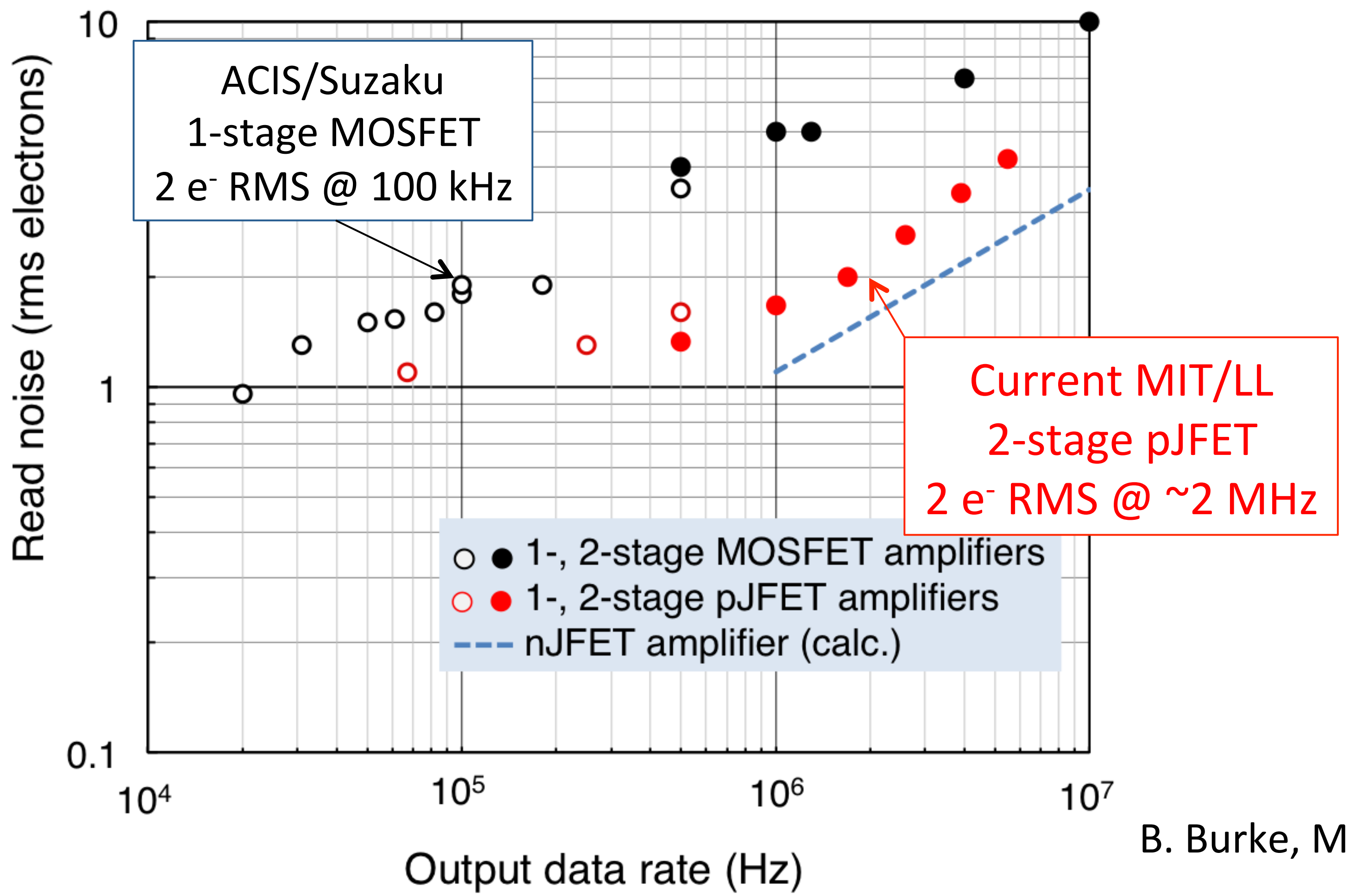
- Expected performance:
  - ~ <5 e^- noise; 50-100μm depletion, back-illumination
- Status:
  * Tier-2 complete; Tier-1 in fabrication
  * Front-illuminated devices within ~ 6 months

Progress in CCD Technology: a middle way

- CCD technology has advanced since Suzaku:
  - Much faster readout at a given noise level
  - Much lower power
  - More flexible architecture for larger focal planes and better radiation tolerance
- These advances can meet near-term technology development needs, e.g., for
  - Faster, low-power XGS readouts for AXSIO
  - Large-area, wide-field detectors for Explorers

Advanced CCD Technology
from MIT Lincoln Laboratory

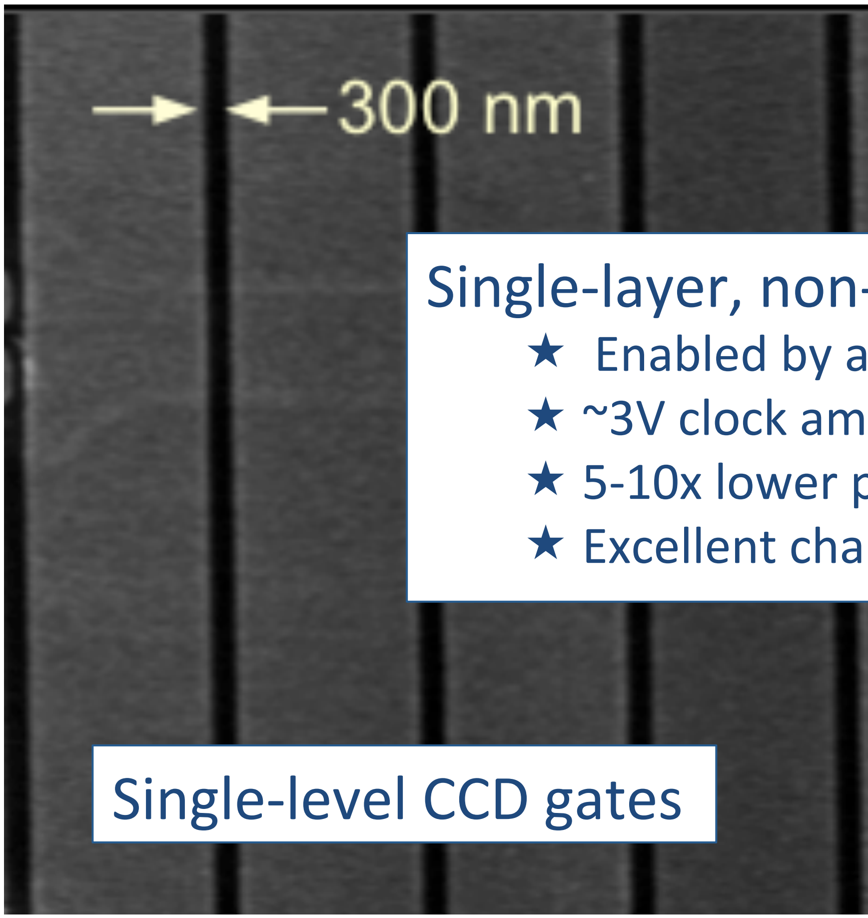
1. 10x faster low-noise output amplifiers



B. Burke, MIT/LL

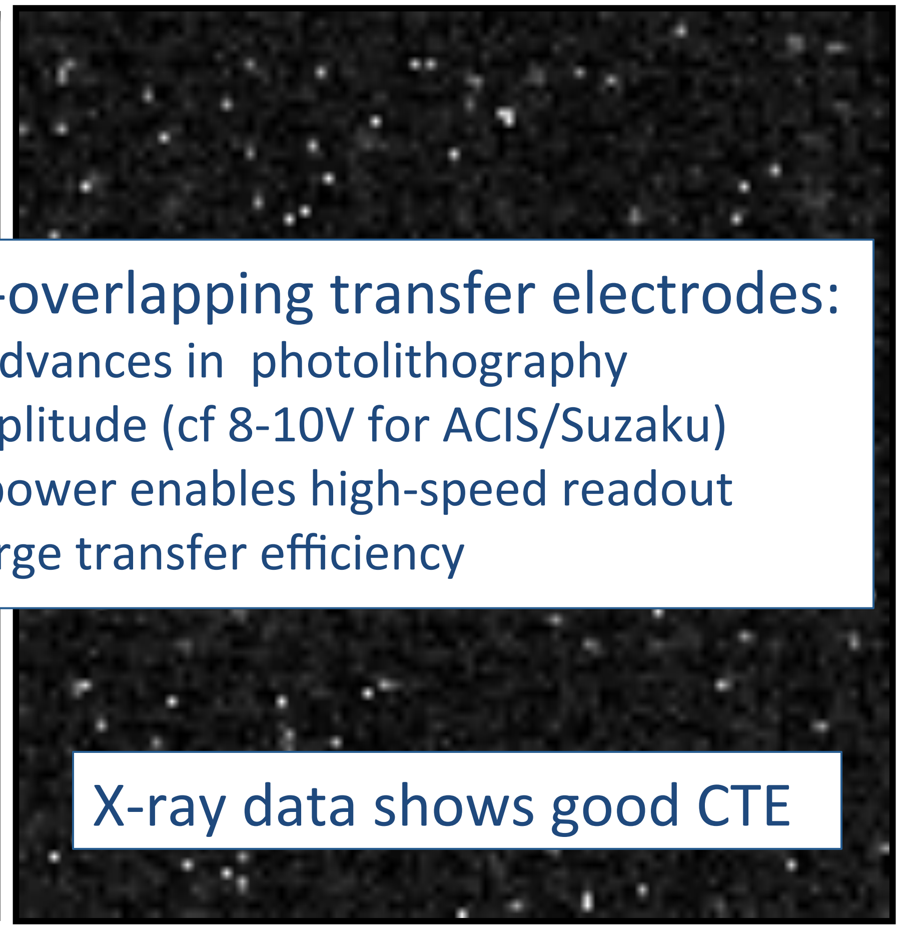
Advanced CCD Technology
from MIT Lincoln Laboratory

2. Low-power, high-speed charge transfer



Single-layer, non-overlapping transfer electrodes:

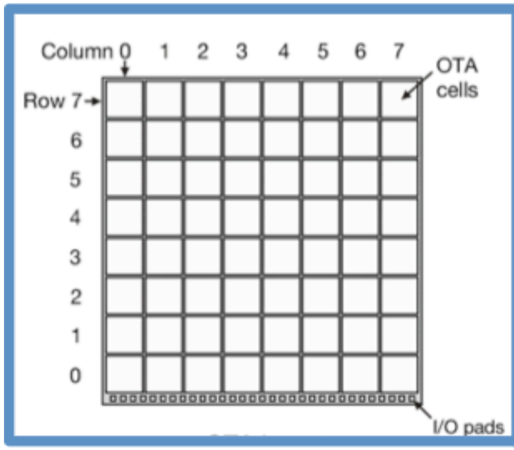
- ★ Enabled by advances in photolithography
- ★ ~3V clock amplitude (cf 8-10V for ACIS/Suzaku)
- ★ 5-10x lower power enables high-speed readout
- ★ Excellent charge transfer efficiency

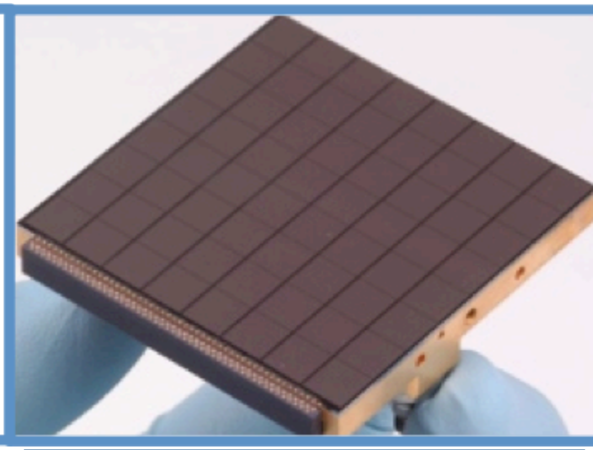


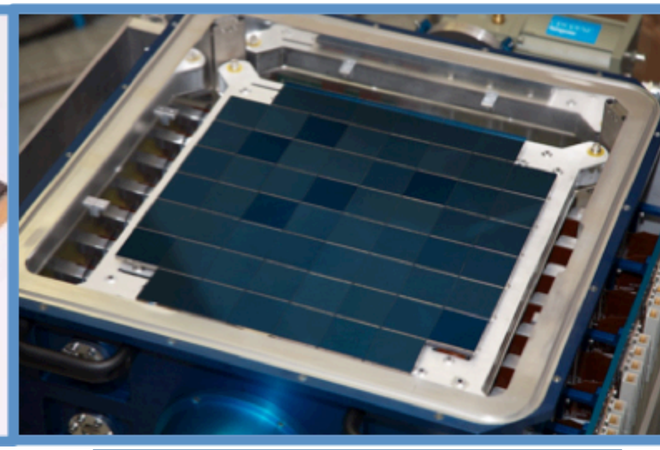
B. Burke, MIT/LL

Advanced CCD Technology
from MIT Lincoln Laboratory

3. Modular, multiplexed CCD architecture







Schematic:
8x8 CCD cells per chip

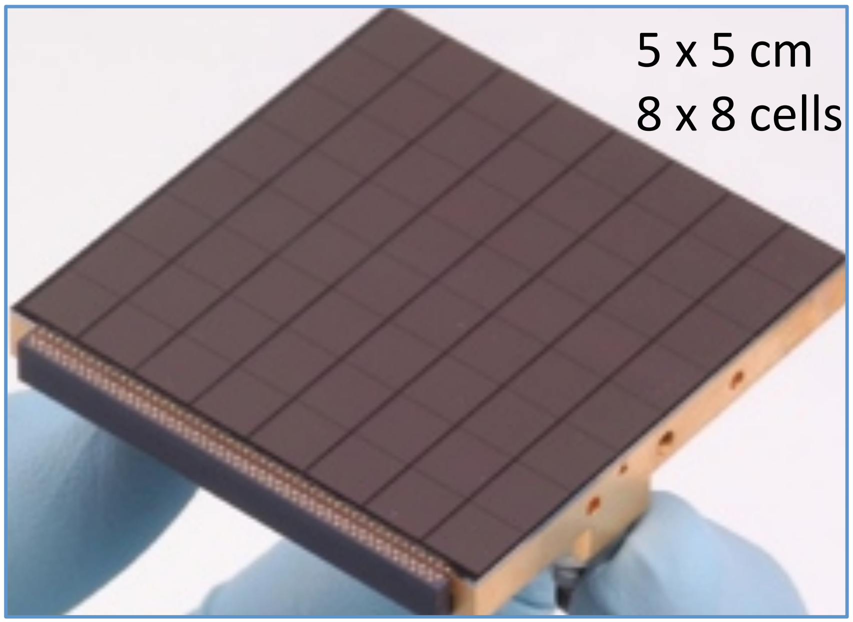
Pan-STARRS detector:
5x5 cm, ~4.8k x 4.8k pixels

Pan-STARRS focal plane:
~400 x 400 mm

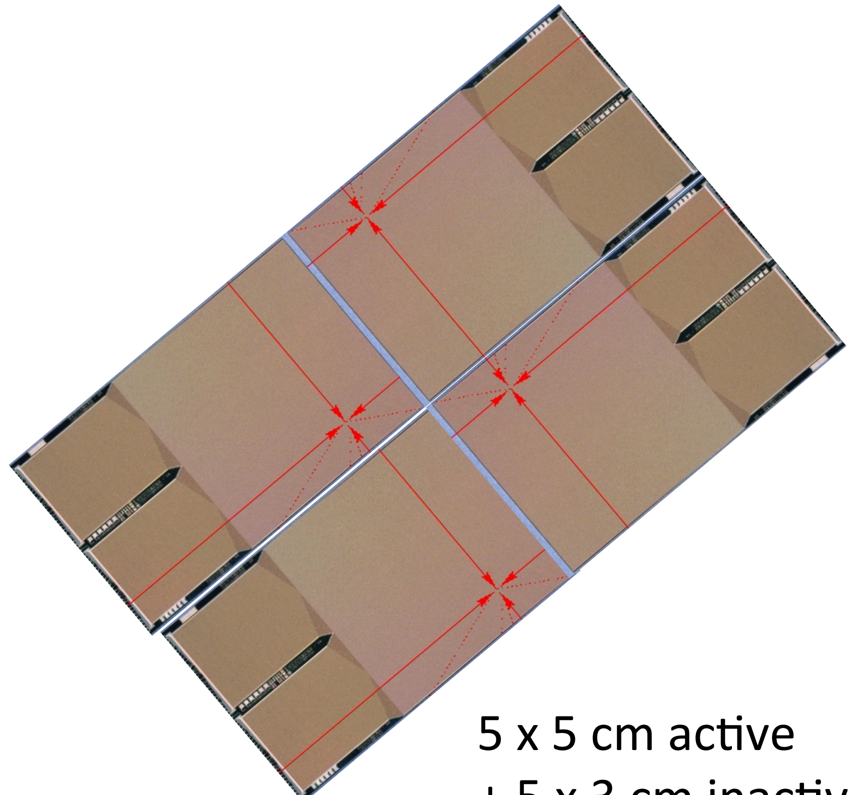
Developed for Pan-STARRS (Tonry, Burke+, 2008)

- ★ Allows large (5 x 5 cm) detectors w/ multiple CCDs (cells) on one chip
- ★ Multiple parallel outputs for higher speed readout
- ★ Four-side abuttable to tile very large focal planes
- ★ Small cells minimize transfer distance, improve radiation tolerance
- ★ Modular: cells can be assembled in multiple configurations

Modular and ACIS/Suzaku CCDs



Pan-STARRS modular CCD



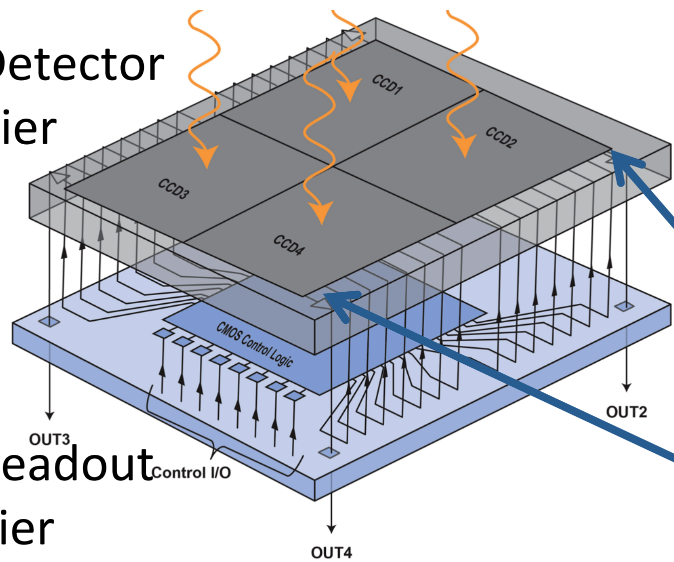
5 x 5 cm active
+ 5 x 3 cm inactive

ACIS-I Focal Plane

Modular 3-D Advanced CCD Now in Fabrication at MIT/Lincoln

Test Device Configuration

Detector Tier

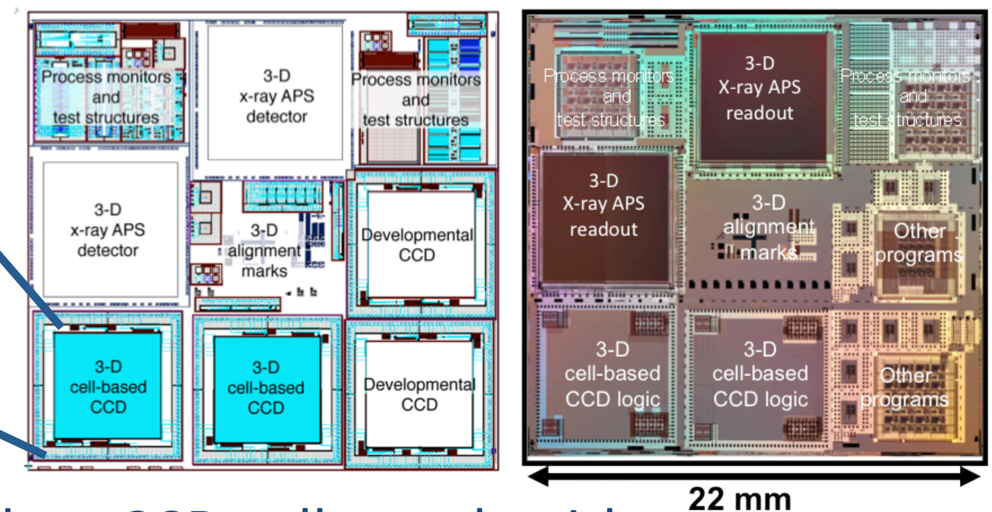


Readout Tier

Die Layouts

Detector Tier

Readout Tier

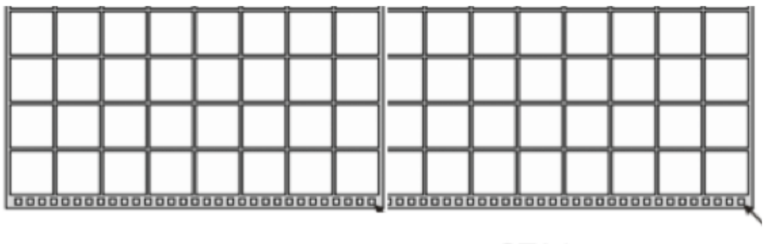


2 x 2 independent CCD cells, each with:

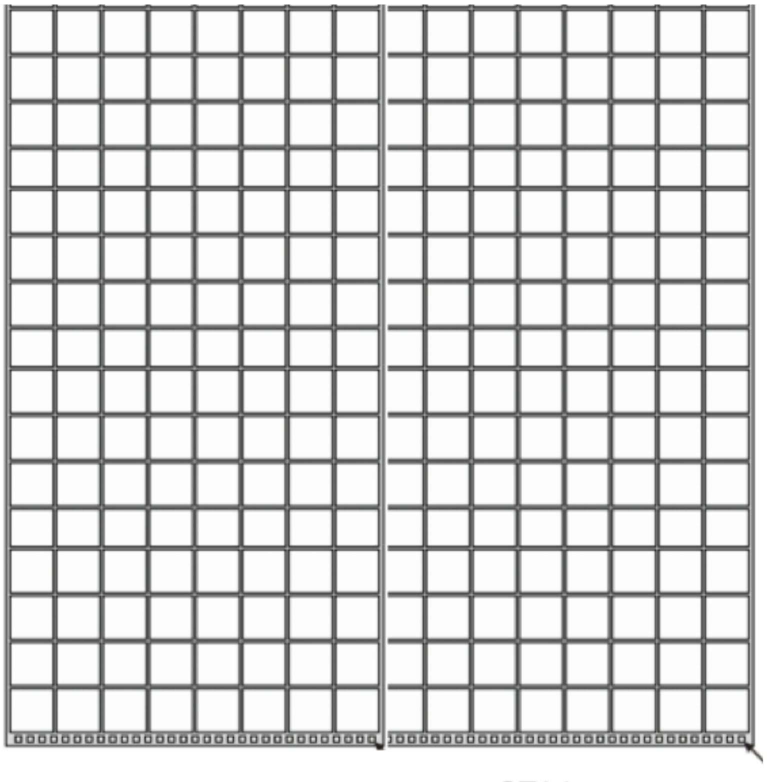
- 512 x 512 pixels, 4.8 µm square
- High-speed low-noise amplifiers
- High-speed, low-power transfer gates

Modular Architecture Supports Multiple Applications

For X-ray Grating Spectrometer



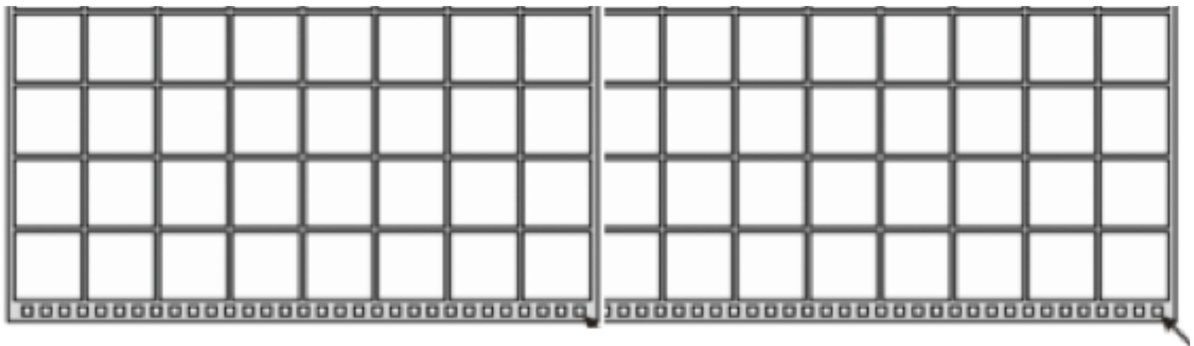
For Wide-field Explorer



- Single CCD cell module design serves multiple applications
- Cell array tailored for each application
- Reduces design cost and risk, increases TRL

Modular Architecture Supports Multiple Applications

X-ray Grating Spectrometer Detector



- 4 x 16 independent CCD cells; 10 x 40 mm
- 15 Hz frame rate meets AXSIO requirement
- Power consumption 20% of Suzaku-based AXSIO XGS
- Electronics mass 25% of Suzaku-based AXSIO XGS
- Radiation tolerance 10x better than ACIS

Summary

- CCD technology continues to progress
- This progress offers important benefits to X-ray astronomy:
  - * Achieves performance requirements
  - * Reduces power & mass, increases reliability
- Effective technology development planning must allow for unplanned technical progress