High Definition X-ray Imager (HDXI)

April 2017

Abe Falcone, Ralph Kraft, & Mark Bautz

for HDXI IWG

Overview

- Activity
- Instrument State of the Art
- Plans, Requests for feedback/questions

Activity

- Biweekly IWG telecons since August
- Accomplishments
  - Ratified Charter
  - Defined current state of the art for HDXI
  - Specified sub-charters for each instrument group
  - Invited selected experts to join
  - Addressed some questions from the Chair & from Science groups
- Poised to begin more focused HDXI group meetings and instrument design/trade studies
- *Waiting on requirements from STDT Science WGs*

Instrument State of the Art

- High-Definition X-ray Imager (Falcone/Kraft/Bautz)
  - https://drive.google.com/drive/folders/0B7glf1X5jW5IbEFBQTRCVE9oYmM

Status, Future Developments, and Fundamental Trade-offs for the sensors and electronics of the HDXI

Basic requirements – *to be modified by STDT*!

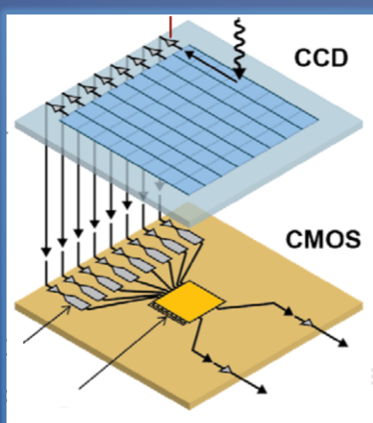
HDXI Parameters/ Requirements	
Energy Range	0.2 – 10 keV QE > 90% (0.3-6 keV), QE > 10% (0.2-9 keV)
Field of View	22' × 22' (4k × 4k pixels)
Pixel size	≤ 16 × 16 micron (≤ 0.33 arcsec)
Read noise	≤ 4 e^-
Energy resolution	37 eV @ 0.3 keV, 120 eV @ 6 keV (FWHM)
Frame rate	> 100 frame/s (full frame) > 10000 frame/s (windowed region)
Radiation tolerance	10 years at L2

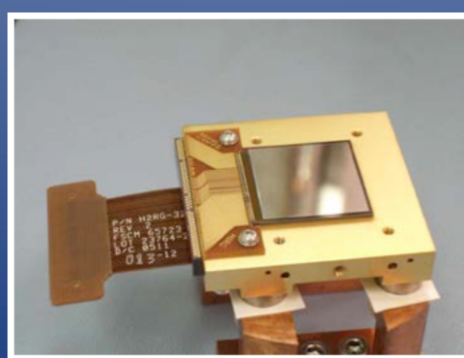
Three active pixel sensor technologies currently under discussion by IWG

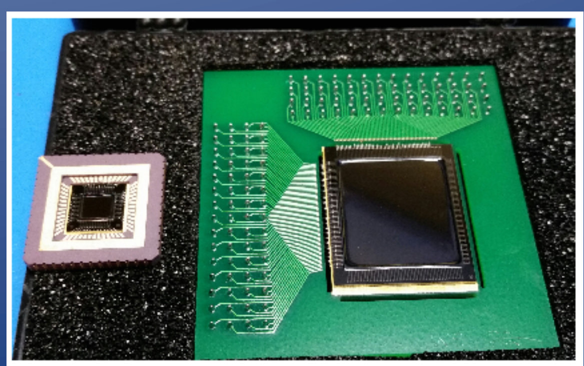
- Digital CCDs (LL/MIT)
- Hybrid CMOS (Teledyne/PSU)
- Monolithic CMOS (Sarnoff/SAO/MPE)

Additional Developments:

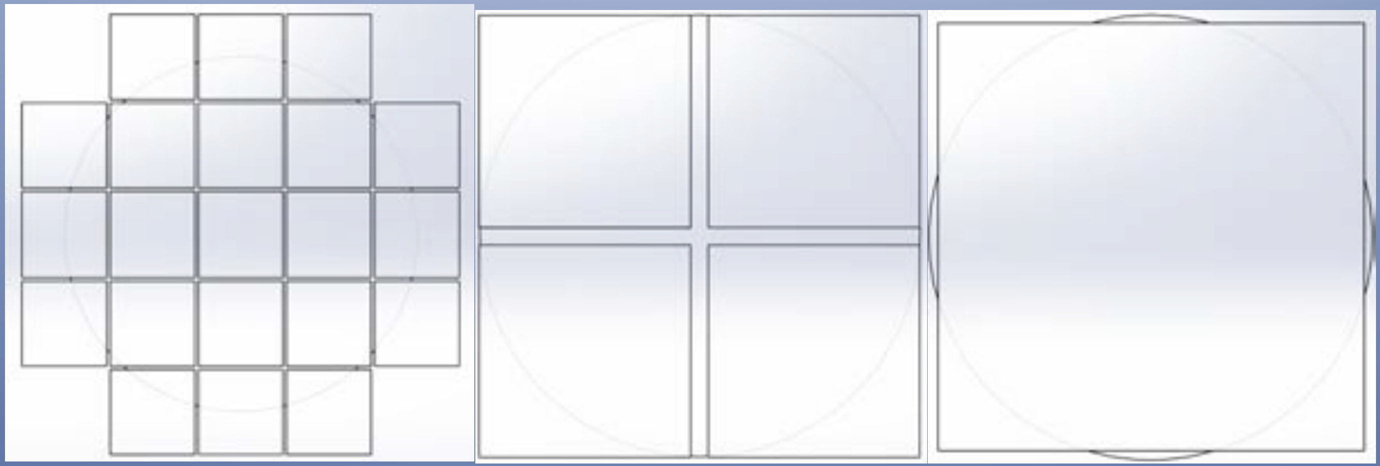
- High Speed Event Processing Electronics
- Ge detectors (?)
- Event-driven detection (?)
- thick devices with sub-pixel resolution







Schematic Detector Layout



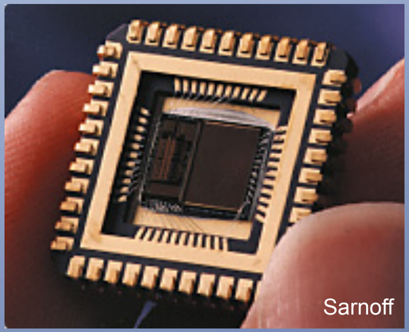
Schematic layout of detector focal plane with 3 options: (a) 21 detectors with 1024x1024 pixels, (b) 4 detectors with 2048x2048 pixels, and (c) 1 detector with 4096x4096 pixels.   The multiple detector options can be tilted to accommodate a curved focal plane surface.

Based on initial ray tracing studies, the curved surface appears to be needed to fully realize the angular resolution offered by mirrors with subarcsec resolution.

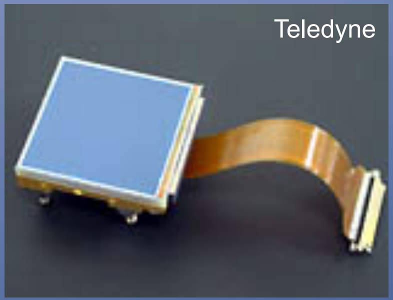
→ *We are baselining a plan that involves a focal plane with multiple detectors.*

3 Different Sensors Approaches

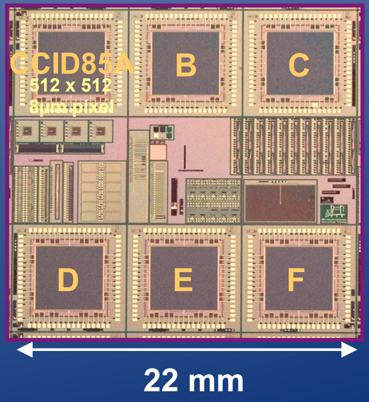
- Monolithic CMOS Active Pixel Sensor
  – Single Si wafer used for both photon detection and read out electronics
  – Sarnoff/SAO and MPE



- Hybrid CMOS Active Pixel Sensor
  – Multiple bonded layers, with detection layer optimized for photon detection and readout circuitry layer optimized independently
  – Teledyne/PSU



- Digital CCD with CMOS readout
  – CCD Si sensor with multiple parallel readout ports and digitization on-chip
  – LL/MIT



Current State of the Art

- All of the key requirements are met by one or more of the sensor technologies
- No single sensor meets them all – lots of work to do!

Key improvements over ACIS and EPIC

- Orders of magnitude higher frame rates (>100 full-frame/sec, >10000 subframe/sec)
- Significantly improved radiation hardness
- Fully addressable (i.e. high speed windowing)
- Near Fano-limited resolution over entire bandpass
- Lower power
- Near room temperature operation
- Large format (up to 4Kx4K abuttable devices)

Key sensor trade-offs

1) Pixel size
   - Small pixel size to oversample PSF decreases energy resolution
   - Small pixels increases number of sensors required to fill focal plane
   - Larger pixels could be used to perform sub-pixel centroiding (this would require deep depletion and multi-pixel events)
2) Deep Depletion
   - Thick devices improve QE above 5 keV but degrade energy resolution below 1 keV
3) Higher Frame Rates
   - Mitigates pileup and *may* improve background rejection, but increases complexity and power of read out electronics

Technical Challenges

- **Quantum Efficiency**: Hybrids have achieved the depletion depths required for high quantum efficiency across the X-ray band, but the monolithic devices still need to make further developments to achieve these depletion depths
- **Read Noise**: Monolithic architectures have achieved low read noise, but hybrids still need to progress further to achieve < 4 e^-
- **Small Pixels/Aspect Ratio**: All devices have achieved small pixel sizes, but further development is needed to do this while retaining other advantages and while limiting impacts of increased charge diffusion due to the increase in the aspect ratio of pixel depth-to-width
- **Rate**: While higher frame rates are already possible with APSs, relative to CCDs, significantly more development is needed to handle the data from these increased frame rates at the focal plane level for short/medium term missions and to achieve the required read noise while simultaneously achieving fast frame rates for the long-term mission requirements (>100 frame/sec for >16 Mpix cameras)

Future work:

- Continue developing detectors along each of the three paths
  - Improve energy resolution (and range) & readout rate of the 3 detector options to achieve XRS requirements, along with low power & radiation hardness
  - Revise planned timeline and budget to achieve TRL 5 and then TRL 6 for the detectors
  - Include decision points for picking a detector type for XRS (decision point will probably be post decadal review)
- Upcoming Studies for HDXI
  - Study pixel size needs across detector (oversampling factor)
  - Study possible smaller pixel detector near FOV center
  - Study use of much larger pixel sizes with deep depletion for sub-pixel resolution
  - Define actual noise requirement. What is deltaE/E requirement?
  - What is required energy range for HDXI?
  - Further refine frame rate and windowed frame rate requirements
    - Consider both pile-up needs and science timing needs traded against read noise impact and/or cost & technology impact
    - Evaluate different detectors abilities for each of these
  - Define path to full instrument TRL 5, & TRL 6
  - Revisit cost estimates for full HDXI instrument
  - Continue to listen to STDT and provide feedback

More Future Work

- Electronics board plan for handling fast event rate and large data throughput; likely to require fast event recognition/characterization on-board
- Grating detectors?
- ....

Plans

- Iterate with STDT to define requirements
  - Establish baseline & goals
  - Identify, develop & articulate tradeoffs for STDT
- Support response function in development
- Refine Hybrid/Monolithic/DCCD comparison & consider any other options
- Evaluate detector electronics requirements & readiness
- Work with XGS on grating readout requirements & configurations
- Work with PCOS to establish technology development priorities for APRA & SAT
- Produce timeline and plans for technology development required for concept study
  - Requires current technology readiness assessment
  - Target: TRL 5 by Decadal; TRL6 by PDR
- Support ACO mission studies
- Broaden community involvement in HDXI IWG
  - Encourage community interest
  - Identify and meet needs for professional support
    (e.g. upcoming Lynx/Industry day in May)
- Prepare for possible IDL and define questions to be answered; we need requirements

Back-up

What could be done as part of Si Sensor HDXI IWG:

1. Work with the STDT to establish baseline instrument and science requirements
    a) STDT to define science requirements – When? Then, we can work to define HDXI instrument requirements − When?
    b) HDXI IWG needs to outline/define technical trades (e.g. energy resolution versus read out rate, energy resolution versus pixel size, energy range, etc.)
2. Clarify future research/technical development path for both sensor and drive/ readout electronics. This will depend to the science requirements sent down by STDT. There are presently 3 groups working on Si sensors with somewhat different goals. Is there anything we collectively are not doing that Lynx will need? Aggressively work with NASA (HQ and PCOS office) to ensure that our technology needs and funding requirements are well-known (and met!). Do we want to push the need for an event-driven system?
3. Participate in all costing/mission design exercises that the STDT does with the ACO. We will need to provide key inputs related to costing and trade-offs (e.g. impact of number of sensors, data rate, cooling -> cost/mass/etc.)
    a) RPK – I was unhappy with costing of ACO study and want to look at this more carefully and assess/compare with recent comps (TESS, Euclid, Kepler, etc.)
    b) Camera design for previous ACO study was very generic. Do we need to improve this? Does this matter?

4. Define TRL of all key components and determine what it would take to get everything to TRL 5 before 2020 Decadal.   Develop comprehensive plan to get to TRL 6 by PDR.
5. Determine what level of engineering support (if any) is required for mission concept studies. We will probably need to get some level of internal MIT/SAO/PSU funding to support this – B&P/IR&D.
6. Define what other members of the HDXI IWG are going to do. This is still at present ill-defined.
7. IDL for HDXI? What questions will we answer with this? Trades will depend on STDT SWG priorities and on the currently unknown instrument requirements.