Beyond Chandra - The X-ray Surveyor
The Future
for High-Resolution X-ray Astronomy

Martin C. Weisskopf & Jessica A. Gaskin – NASA/MSFC
Harvey Tananabaum & Alexey Vikhlinin – SAO
On behalf of the Informal Mission Concept Team

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Why we are Talking about the X-ray Surveyor

- NASA Astrophysics Division white paper: Planning for the 2020 Decadal Survey
  - Provided an Initial list of missions drawn from 2010 Decadal Survey and 2013 Astrophysics Roadmap that includes the X-ray Surveyor
  - Requested the three NASA Program Analysis Groups (PAGs) to coordinate community discussion over next 9 months to review and update the list of missions
  - Instructed that PAG report(s) will be sent to the Astrophysics Subcommittee and then to the Astrophysics Division for selection of mission concepts to study
  - Will result in a appointment of Science and Technology Definition Teams and assignment of a lead NASA Center for each study
- We represent a group of scientists that have some definite ideas as to what the X-ray Surveyor's capabilities could be

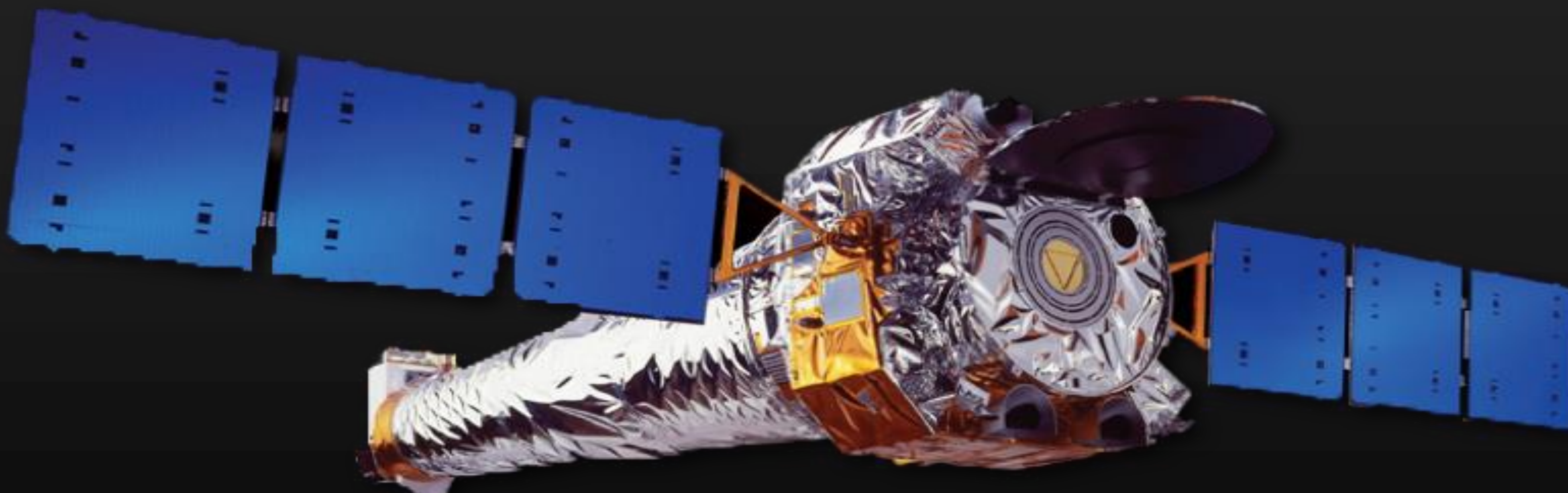
The Informal Mission Concept Team

S. Bandler (GSFC)
M. Bautz (MIT)
D. Burrows (PSU)
A. Falcone (PSU)
F. Harrison (CIT)
R. Heilmann (MIT)
S. Heinz (Wisc)
C. A. Kilbourne (GSFC)
C. Kouveliotou (GWU)
R. Kraft (SAO)

A. Kravtsov (UofC)
R. McEntaffer (U of Iowa)
P. Natarajan (Yale)
S. L. O'Dell (MSFC)
A. Ptak (GSFC)
R. Petre (GSFC)
B. D. Ramsey (MSFC)
P. Reid (SAO)
D. Schwartz (SAO)
L. Townsley (PSU)

Chandra has Provided Unparalleled Means for Exploring the High-Energy Universe

Chandra studies have deepened our understanding of galaxy clusters, active galaxies, galaxies, supernova remnants, normal stars, planets, and solar system objects



The key to *Chandra's* success has been the ½ arc-second angular resolution

It is also clear that many Chandra observations are extremely photon-limited

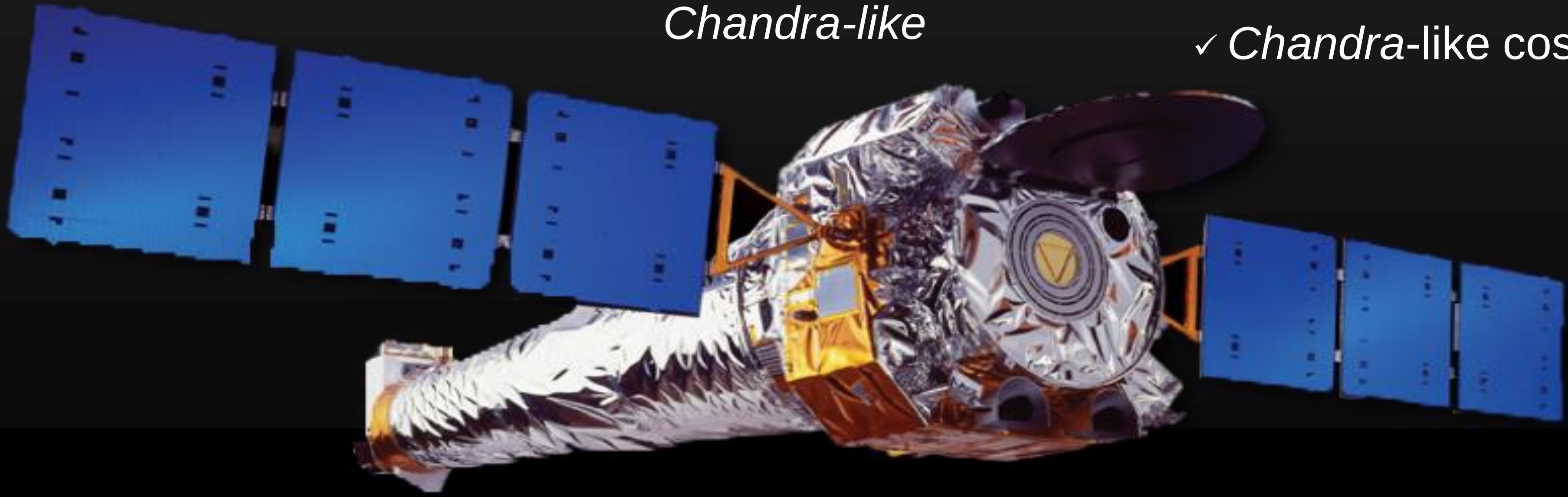
The Baseline X-ray Surveyor Concept is a Successor to *Chandra* that:

- Has angular resolution at least as good as *Chandra*
- Has much higher photon throughput than *Chandra*

✓Incorporates relevant IXO+ development and *Chandra* heritage

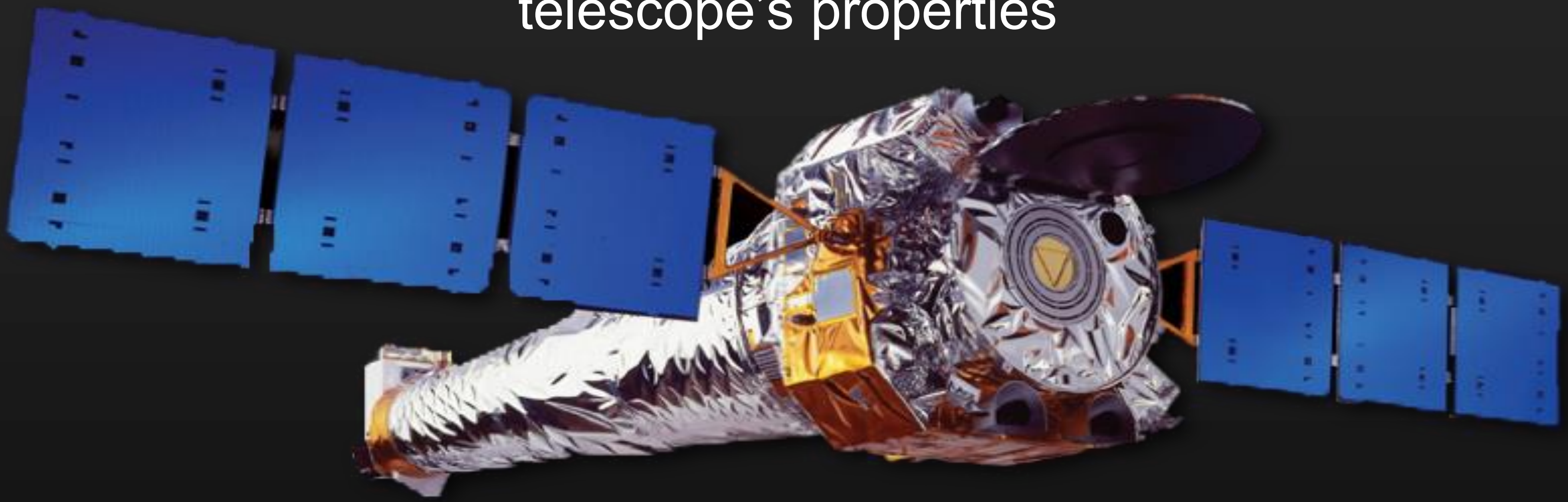
✓ Limits spacecraft requirements to *Chandra-like*

✓ *Chandra*-like cost



The *Baseline* X-ray Surveyor Concept is a Successor to *Chandra* that:

Makes use of next-generation instruments that exploit the new telescope's properties



Strawman payload

5′ × 5′ microcalorimeter, 1″ pixels, 0.2–10 keV

22’ × 22′ CMOS imager with 0.33″ pixels, 0.2–10 keV

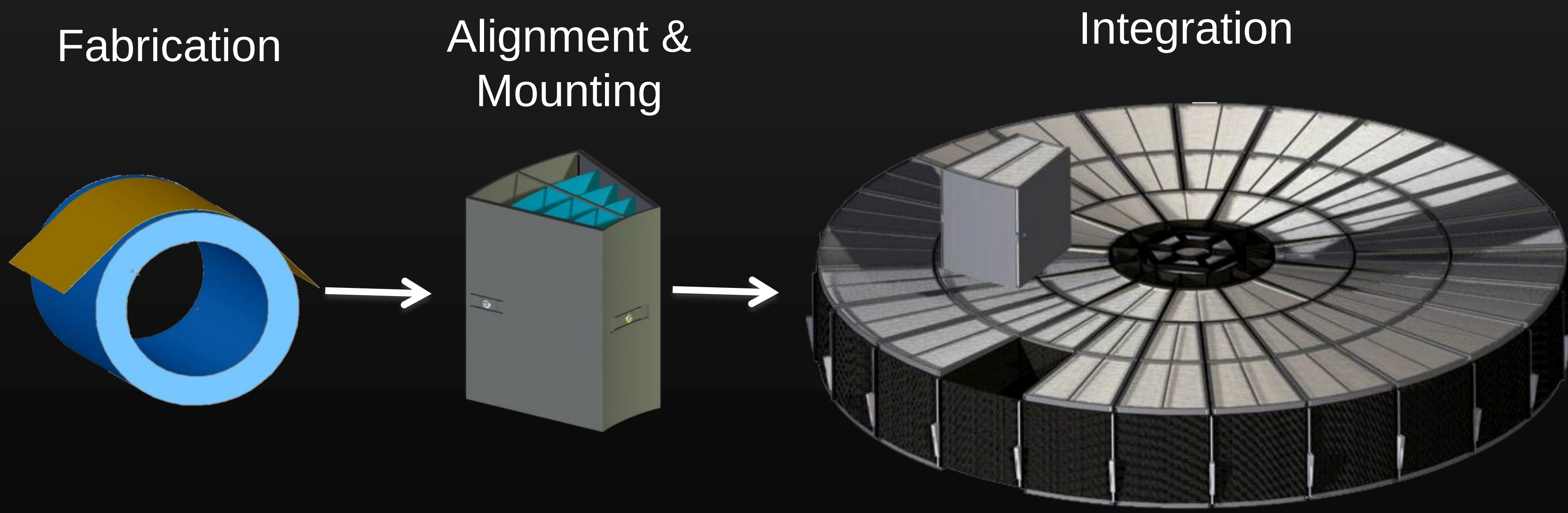
Gratings, R = 5000, 0.2–2.0 keV

How will the Optics be Achieved?

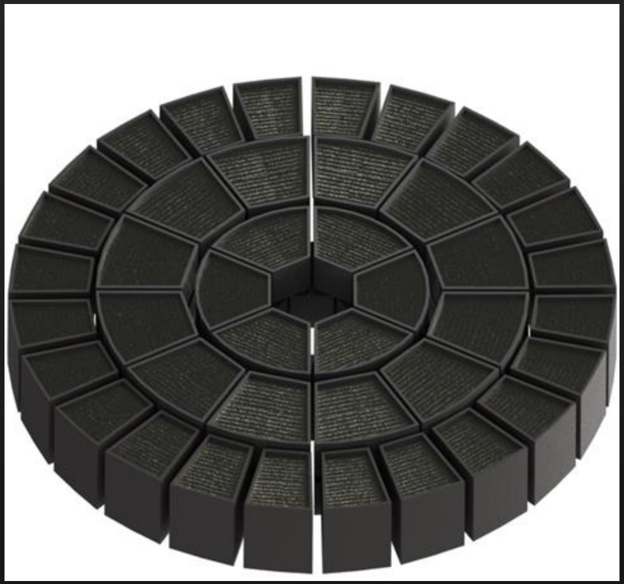
- Build upon segmented optics approaches that were considered for the Constellation-X,…, IXO, AXSIO concepts
- Follow multiple technology developments
  - Several look promising
  - But no one has (yet) demonstrated light-weight sub-arcsecond optics
  - We must do this by 2019

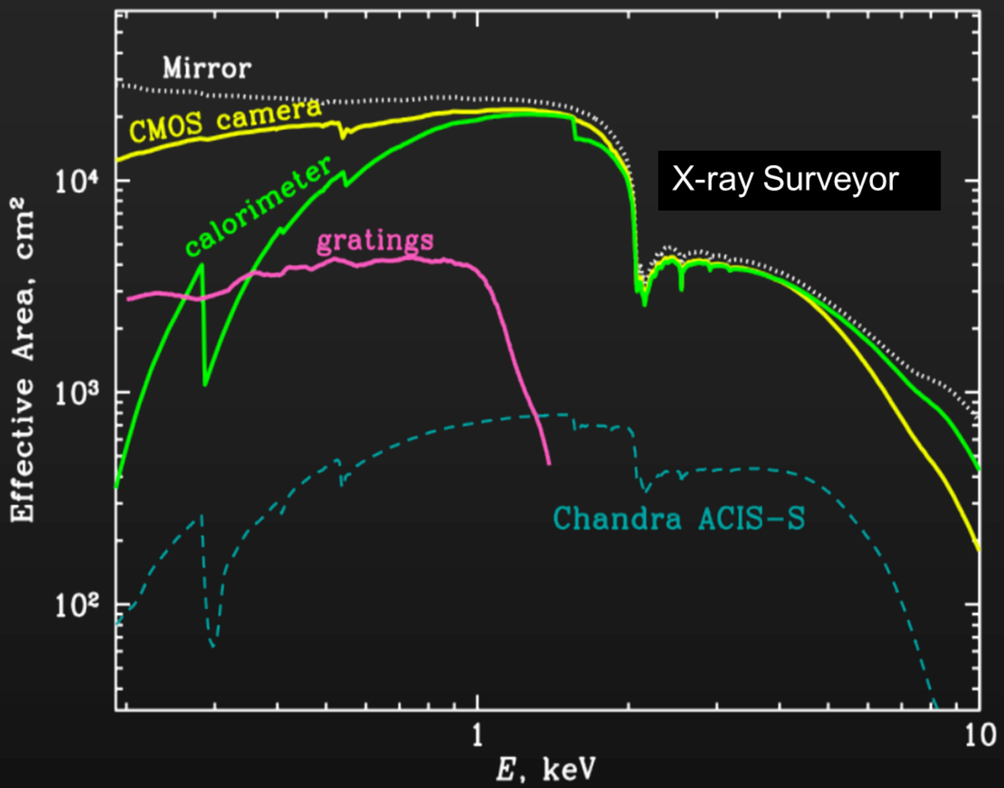
Build on NASA- Sponsored Heritage

The NASA segmented optics approach for IXO was progressing but limited to ~10″ angular resolution



Surveyor Optics: Specifications & Performance

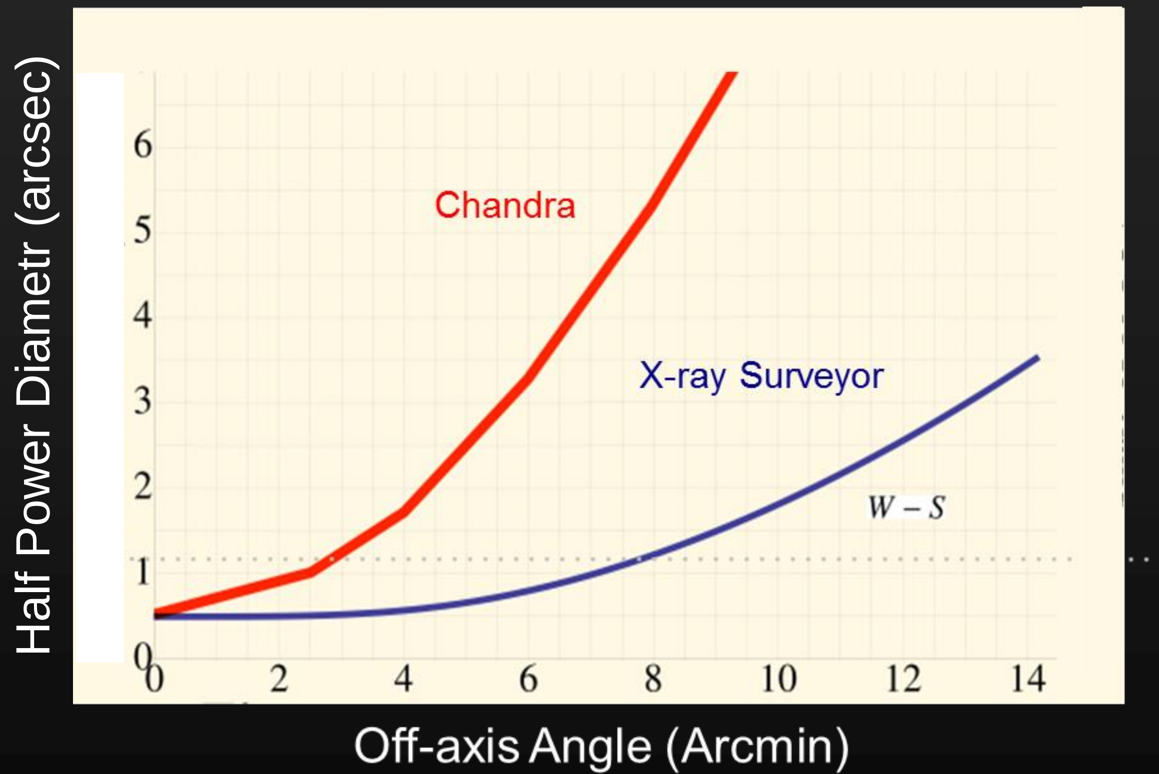




- 292 nested shells, 3m outer diameter, segmented design
- Wolter-Schwarzschild optical scheme
- 30 × more effective area than Chandra
- 4-Msec detection limits below 3×10^{-19} erg/s/cm^2 (0.5–2 keV)

Angular Resolution Versus Off-Axis Angle

Short segments and Wolter-Schwartzschild design lead to excellent wide-field sensitivity



- 10 × larger solid angle for sub-arcsecond imaging
- 500 × higher survey speed at the CDFS limit

Obtaining the Sub-Arcsecond Elements

APPROACHES

- Differential deposition
    - Fill in the valleys (MSFC/RXO)

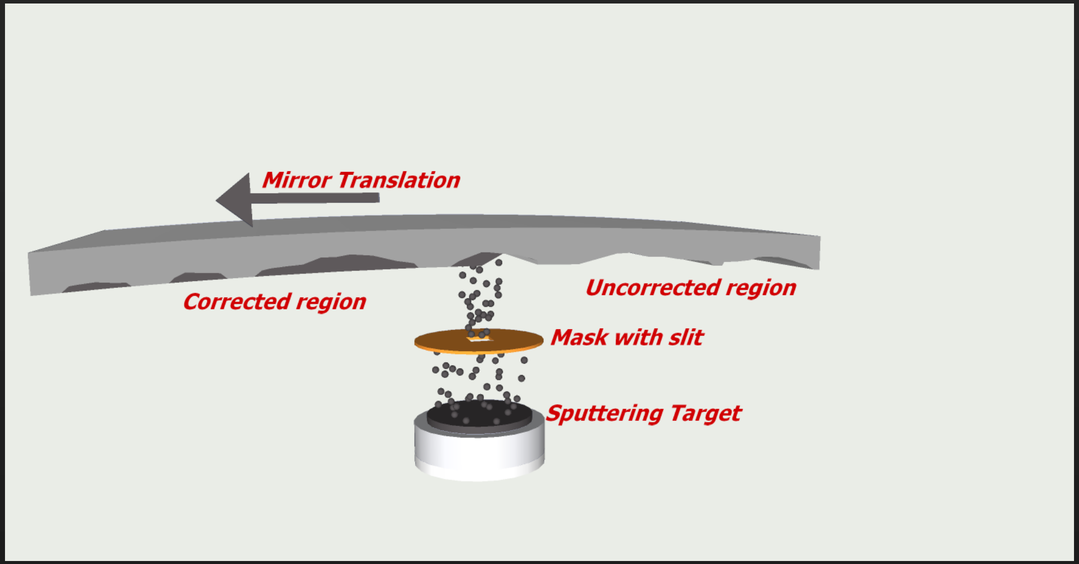
- Adjustable optics
    - Piezoelectric film on the back surface (SAO/PSU)
    - Magneto-restrictive film on the back surface (NW)

ALSO WATCH

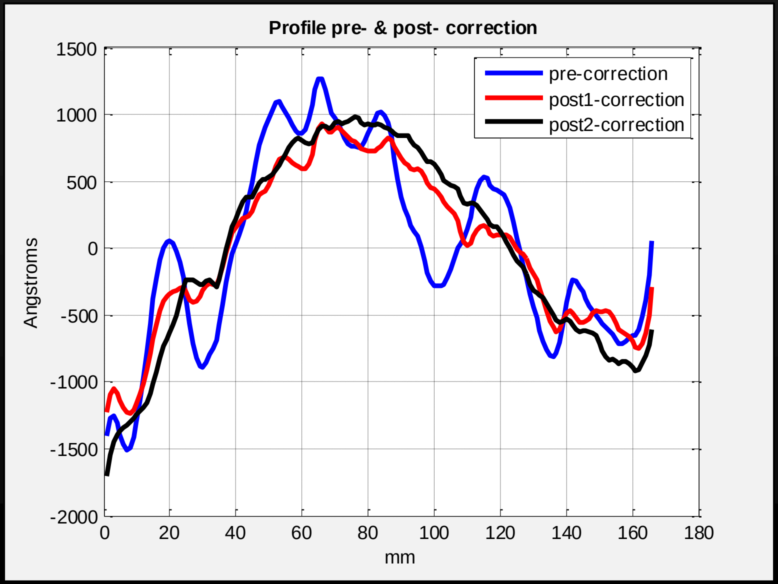
- Slicing and forming thin polished silicon (GSFC)

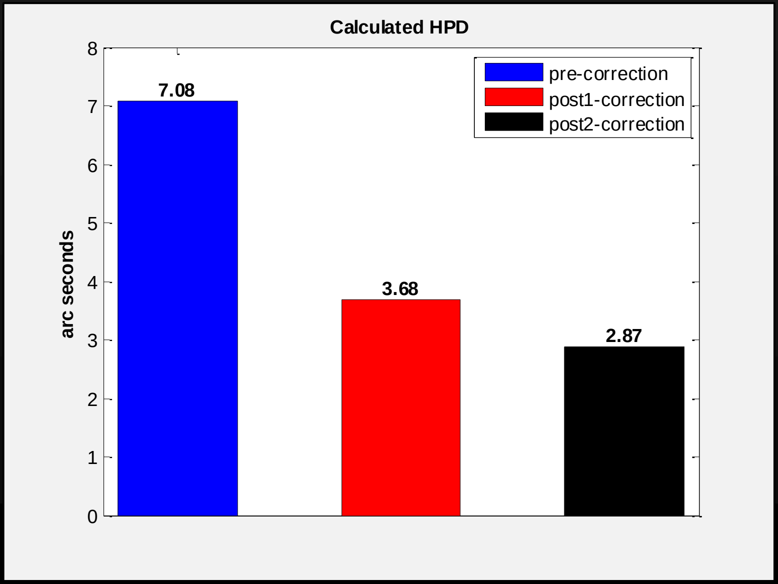
Final approach may well be a combination of the above

Differential Deposition (MSFC/RXO)



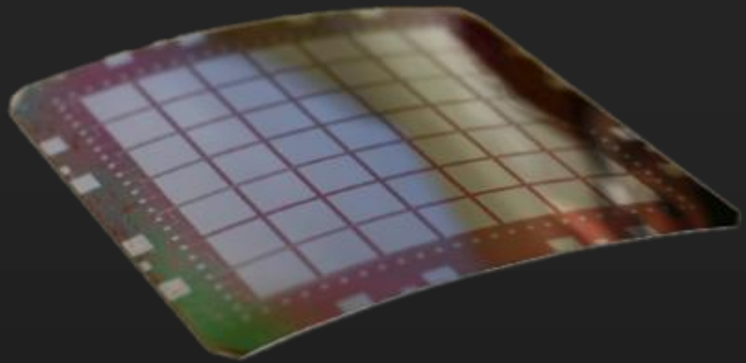
7.1″ to 2.9″ (HPD – 2 reflections) in two passes

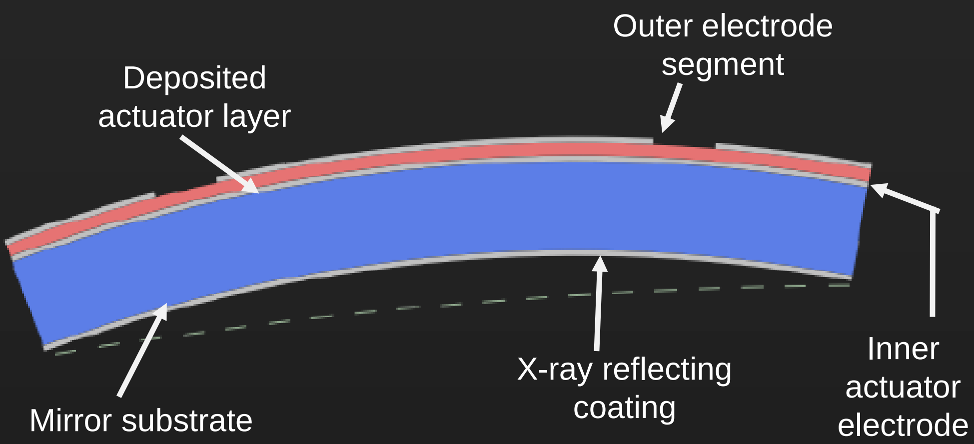




Status --- see next talk

Adjustable Optics – Piezoelectric (SAO/PSU)





- Micron-level corrections are induced with <10V applied to 5–10 mm cells
- No reaction structure needed
- High yield — exceeds >90% in a university lab
- High uniformity — ~5% on curved segments demonstrated
- 2D response of individual cells is a good match to that expected from model
- Uniform stress from piezo deposition can be compensated by Ir coating
- No significant small-scale distortions introduced by the piezo cell deposition

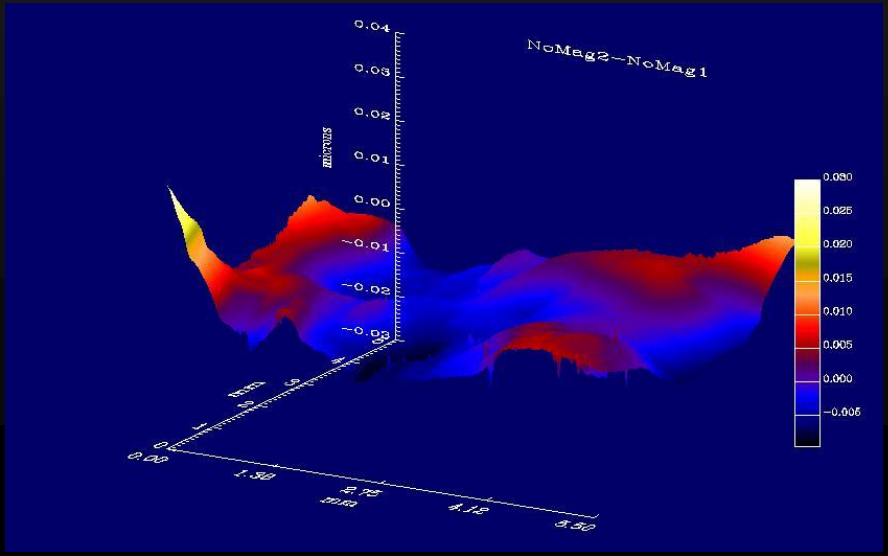
Adjustable Optics - Magnetostrictive (NW)

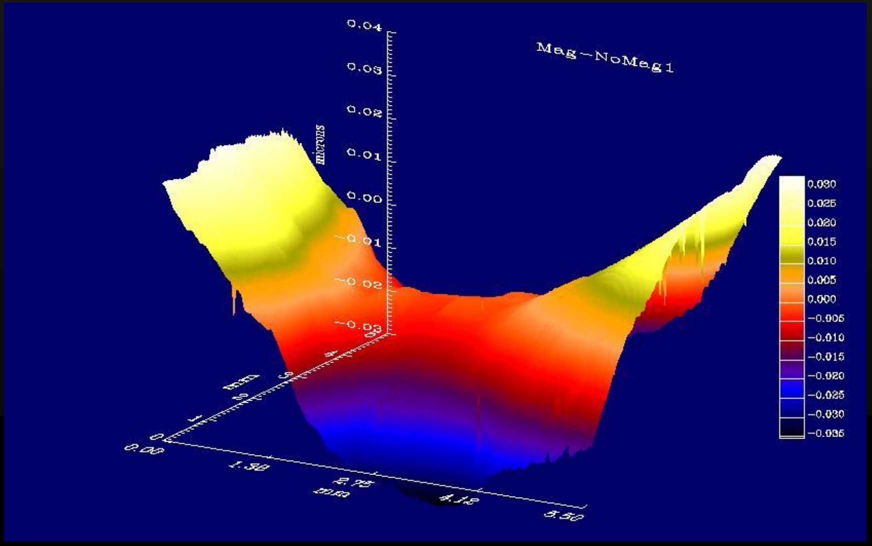
Magnetic smart material applied to NiCo, a magnetically hard substrate 5 mm x 20 mm x 100 µm, showed:

- The material responds to the external field and bends
- Once the external field is removed the piece stays bent

Magnetic field applied to magnetostrictive-coated glass substrate 50 mm x 50 mm x 100 µm showed:

- Repeatability on sub-micron scales
- Capability of bending the piece

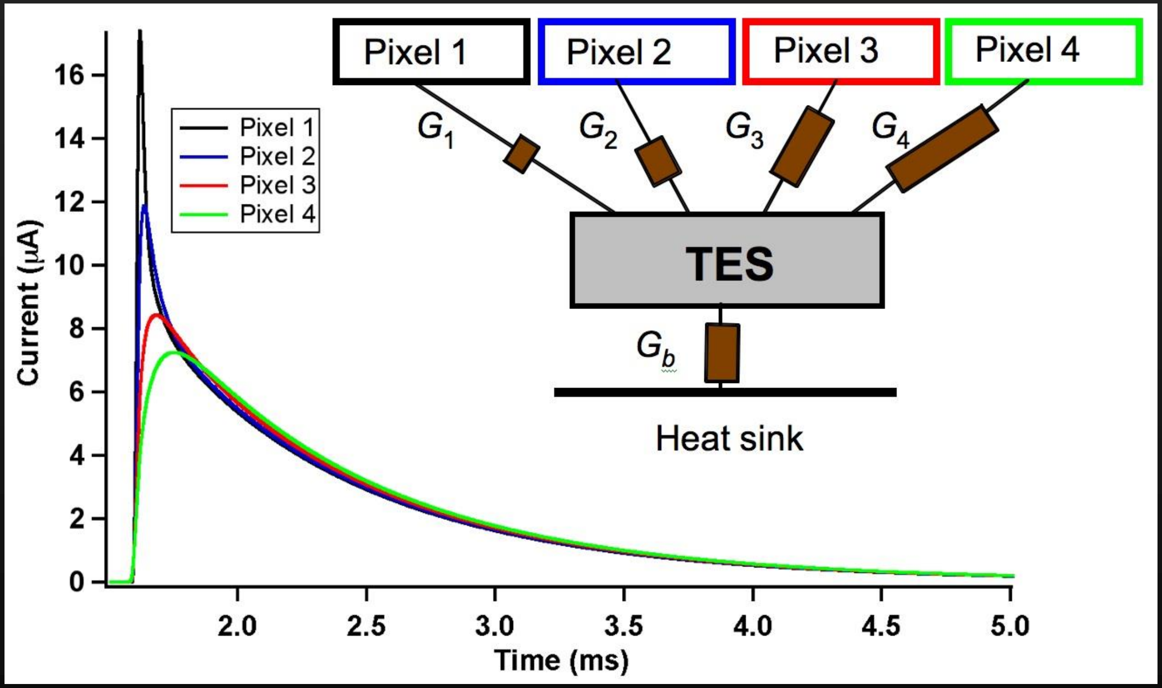




Microcalorimeter Imaging Spectrometer

- 1″ pixels and at least 5′ × 5′ field of view (>90,000 pixels)
- < 5eV energy resolution, 1cnt/s/pixel

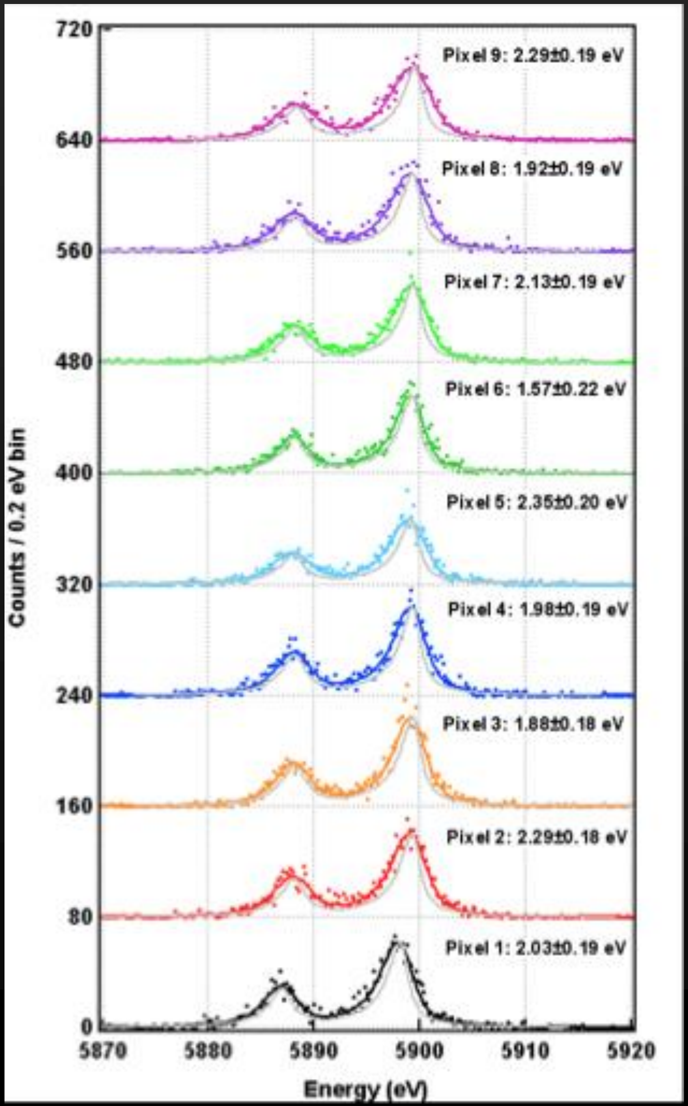
- Conceptual design by S. Bandler et al. (GSFC&NIST):
- Transition Edge Sensors with SQUID readout.
- Multiplexing is feasible via multiple absorbers per one TES ("Hydra"design)



Microcalorimeter Imaging Spectrometer

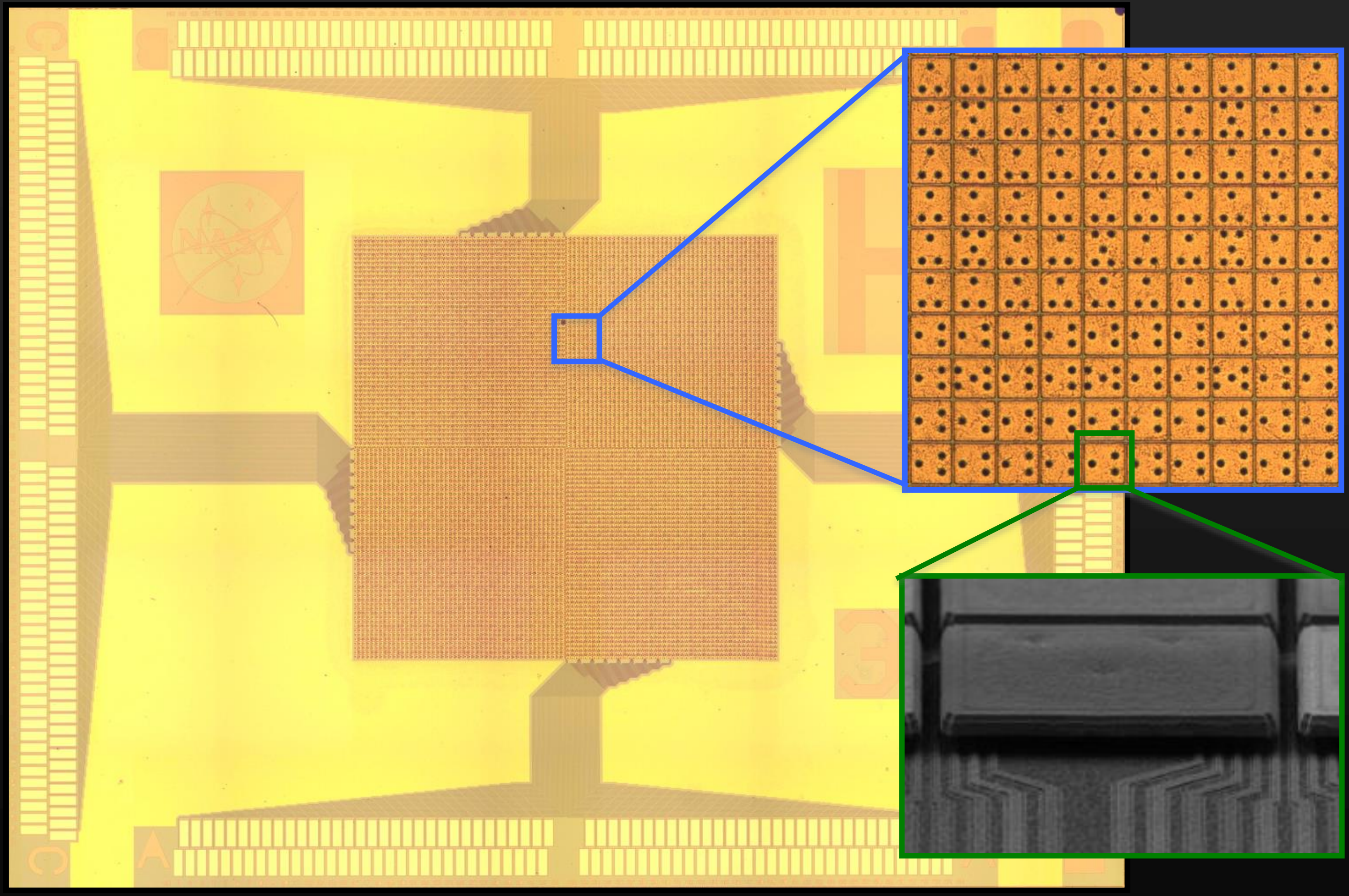
Energy Resolution (w 3 x 3 Hydra)

- Current lab results with 3 × 3 Hydra, 65μm pixels on 75 micron pitch shows 2.4 eV resolution at 6 keV
    - Varied from 2.2 eV @ 1.5 keV to 3.4 @ 8 keV
- ΔE/E ~ N for N × N Hydras, so current results imply ~5 × 5 Hydras with 50μm pixels and < 5eV energy resolution are reachable



Microcalorimeter Imaging Spectrometer

Towards the pixels

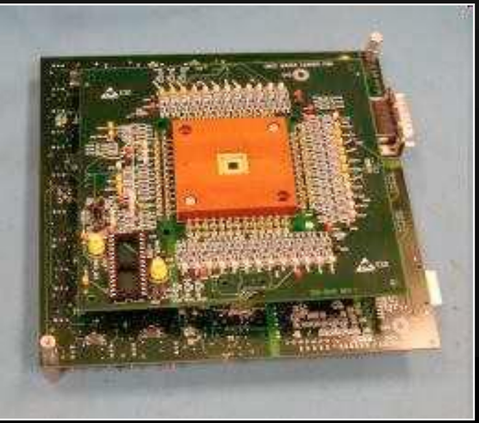


96 x 96 array - fully wired within array – absorbers on 75 μm pitch
- 32 x 32 array of 3x3 Hydras

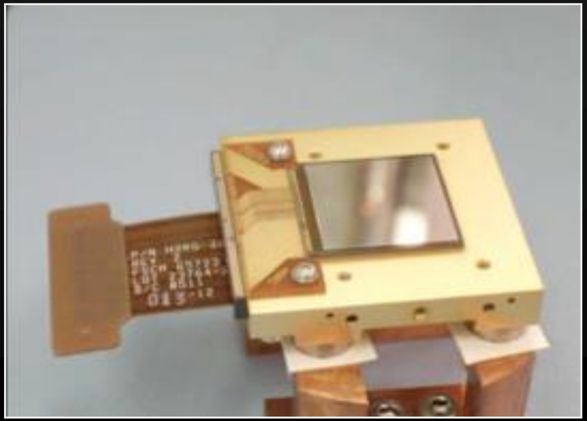
Active Pixel Sensor Imagers

Work is progressing on CMOS-based devices with high throughput, radiation hard, with event driven readout, and windowing capability

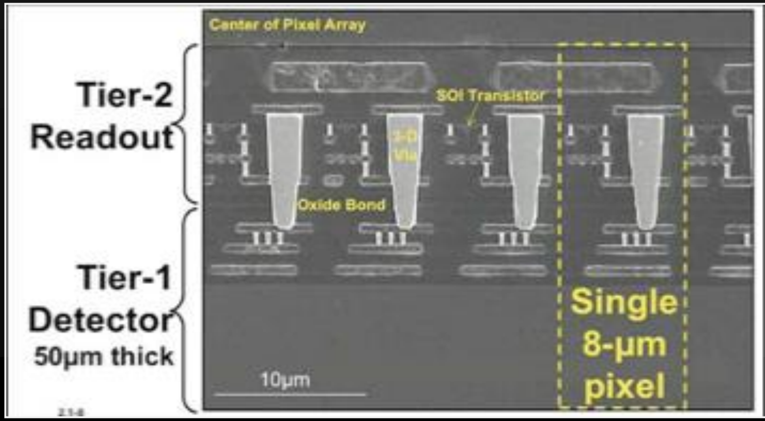
- *X-ray Surveyor needs*
  - 16 μm (= 0.33 arcsecond) pixel size or smaller
  - 4k × 4k array (22′ × 22′ FOV) or bigger
  - Goal of Fano-limited resolution: 33 eV @ 0.5 keV, 48 @ 1 & 120 @ 6
  - QE > 90% (0.3-6.0 keV)



SAO/Sarnoff



PSU/Teledyne

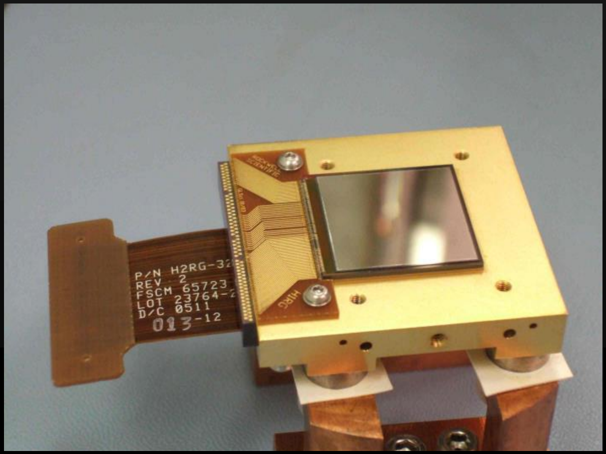


MIT/Lincoln Lab

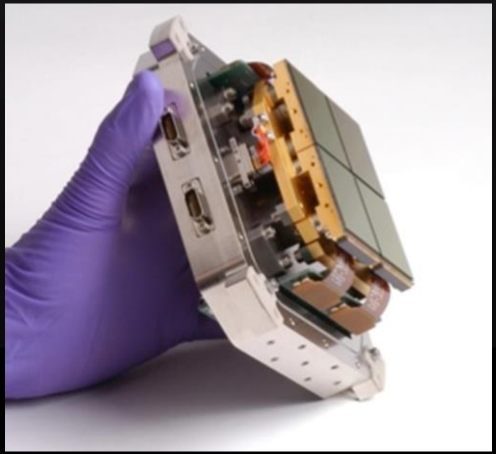
Active Pixel Sensor Imagers: PSU/Teledyne

- PSU/Teledyne back-illuminated with >200 micron fully depleted depth operating over the 0.2–15 keV band
- Teledyne H4RG: 4k × 4k pixels, 15 micron pixels, abuttable design, integral optical blocking filter, guide window, ~8e- read noise (Prieskorn et al. 2013)
- HxRG detectors suffer from pixel crosstalk. Recent work has shown that crosstalk becomes negligible when using Capacitive Transimpedance Amplifiers (CTIA) (Griffith et al. 2014)

H1RG X-ray detector



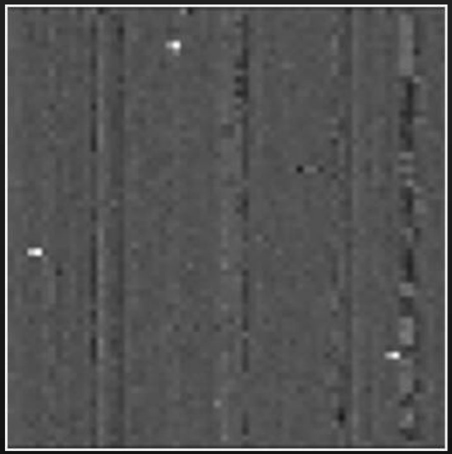
Teledyne detector mosaic

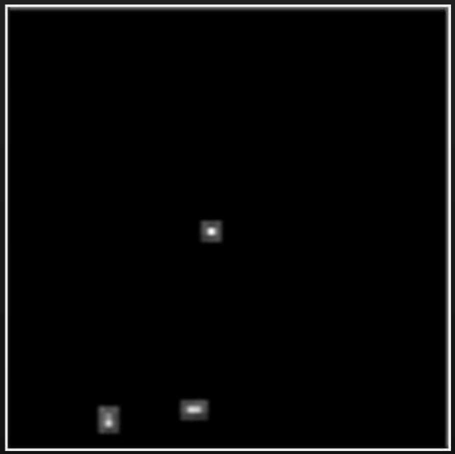


Active Pixel Sensor Imagers: PSU/Teledyne

- 64 × 64, 40 µm pixel device with event driven readout, CTIA amp; 10^5 cnt/s peak rate, 240 eV energy resolution at 6 keV (Griffith et al. 2014). Being expanded to 2 cm x 2cm.

Detector images showing event driven readout (right) (G





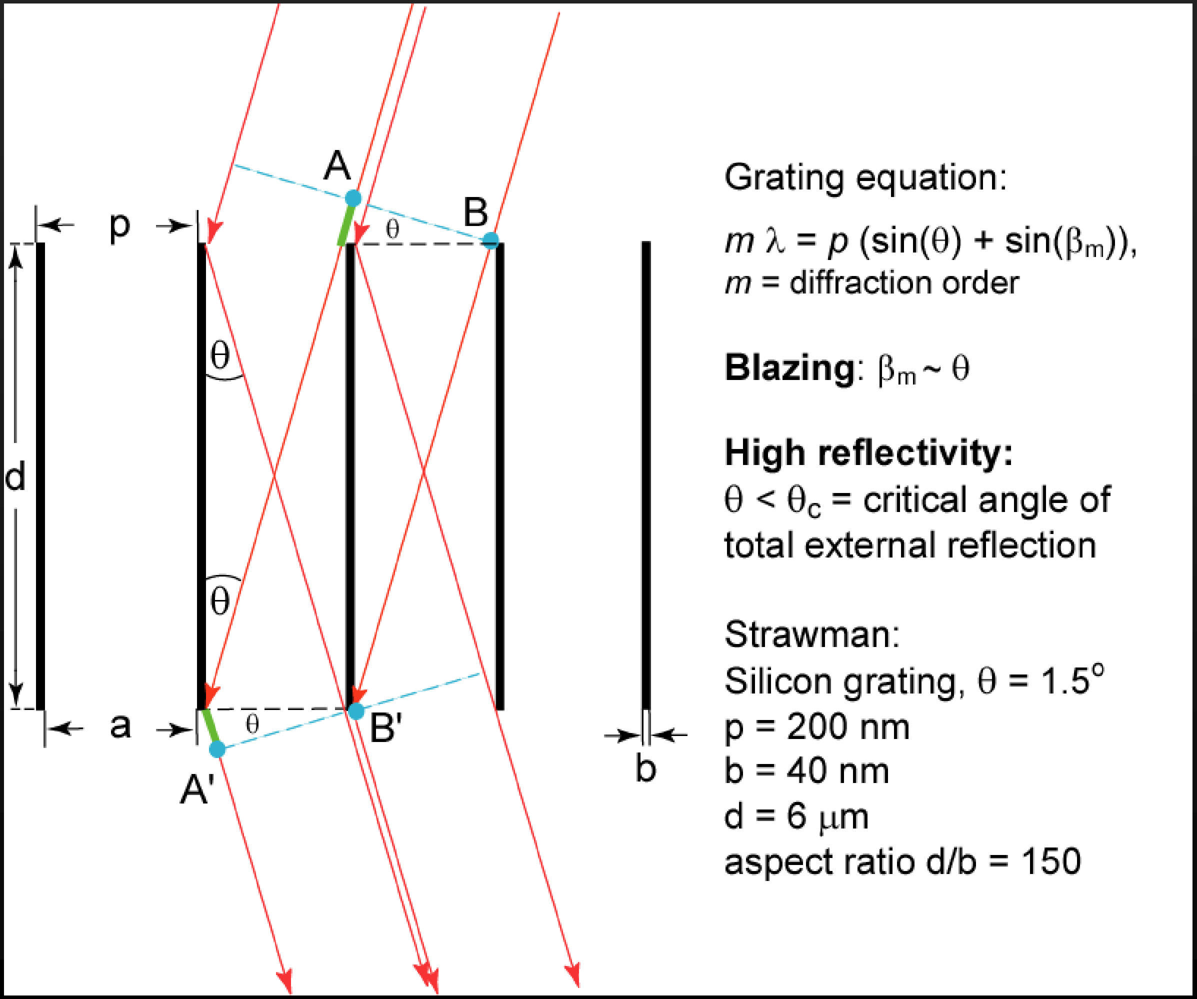
- Smaller pixels (<15 µm) are needed for X-ray Surveyor so PSU/Teledyne has completed an initial design of a Si hybrid CMOS detector with 15 µm pitch pixels, CTIA amplifiers, guide window, and in-pixel Correlative Double Sampling

Transmission Gratings

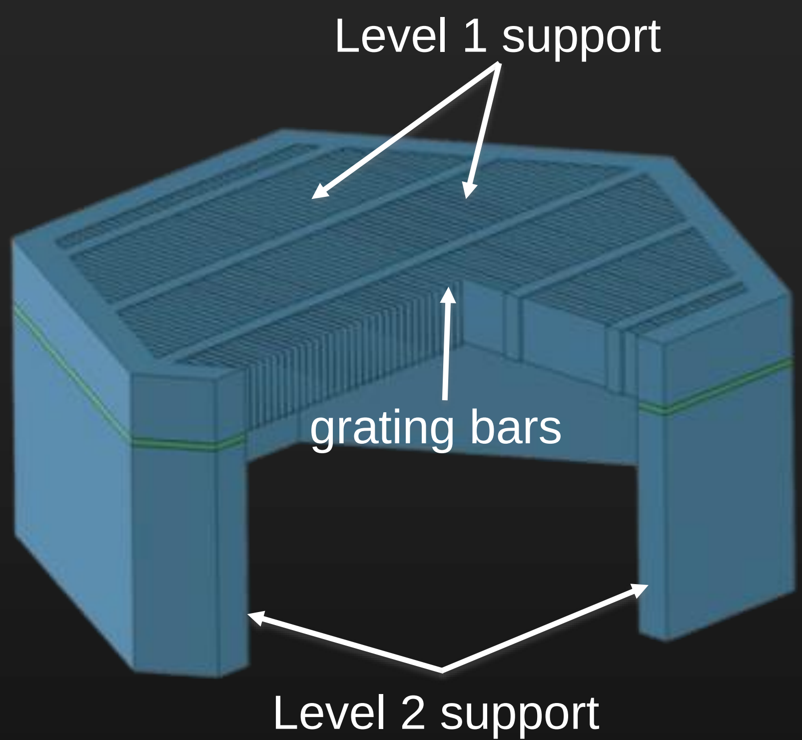
- Area = 4000 cm^2
- Resolving power = 5000
- Energy range 0.2 – 2.0 keV
- Critical Angle Transmission (CAT) Gratings (MIT)
- Blazed Off-Plane Reflection Gratings (Univ. of Iowa)

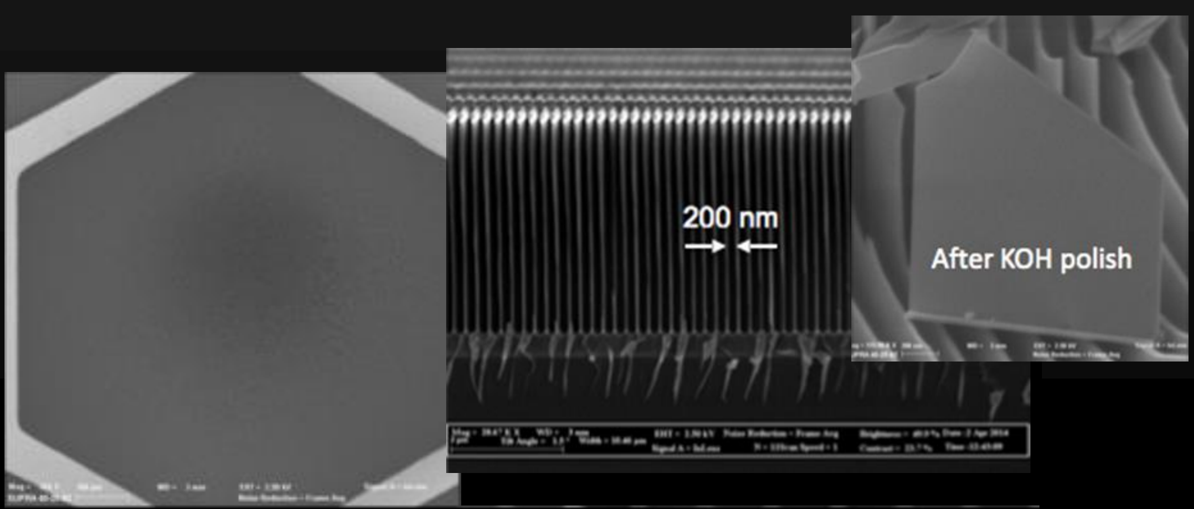
Critical Angle Transmission Grating: Principle

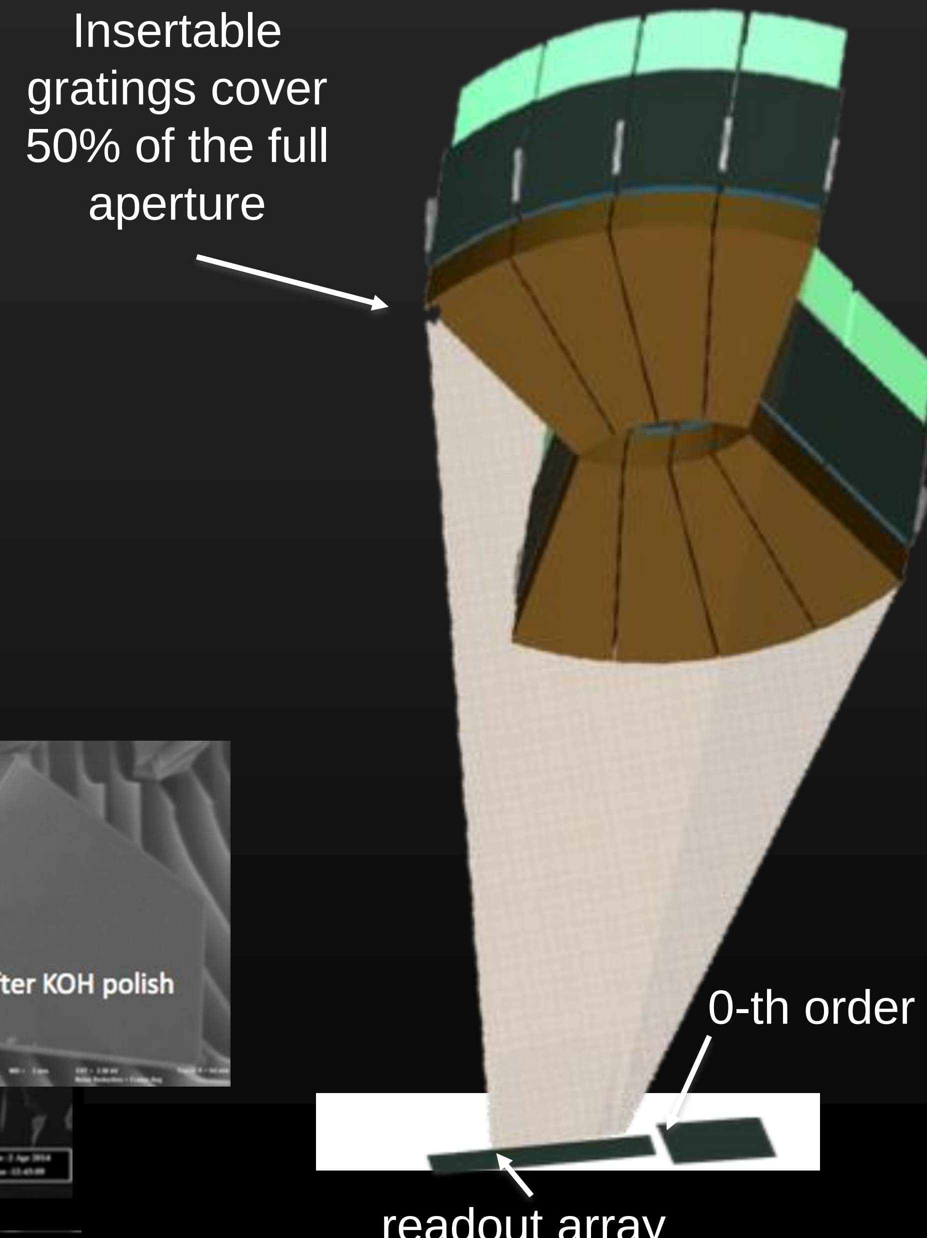
- Combines transmission and blazed grating
- Blazing achieved via reflection from sidewalls at graze angles below the critical angle
- High energy X-rays contribute to effective area at focus



Critical Angle Transmission Gratings (MIT)







Deep Survey Comparison

View the first accretion light in the Universe seeing X-rays from supermassive black holes at early stages of their growth

Chandra at its flux limit in 4 Msec detected:
69 sources
32 galaxies
37 AGN
Over a 3’ x 3’ fov

Surveyor at its flux limit in the same integration time will detect:
12831 sources
11061 galaxies
1765 AGN
Over a 15’ x 15’ fov

Plans (2015)

- MSFC committing Center resources for system level mission studies and initial cost estimates
- Informal Concept Definition Team continue to provide guidance and technical inputs to MSFC's Advanced Concepts Office
- The ICDT will produce a white paper for the NASA Program Advisory group (PAG) process
- MSFC with SAO will sponsor a science workshop to sharpen and broaden the science case

- Near-term objective to generate a technically credible and scientifically compelling concept with broad-based support of the astronomy community to ensure selection by NASA for study starting late this year

- Eventual goals are a top-ranking by 2020 Decadal and launch as close to 2030 as possible