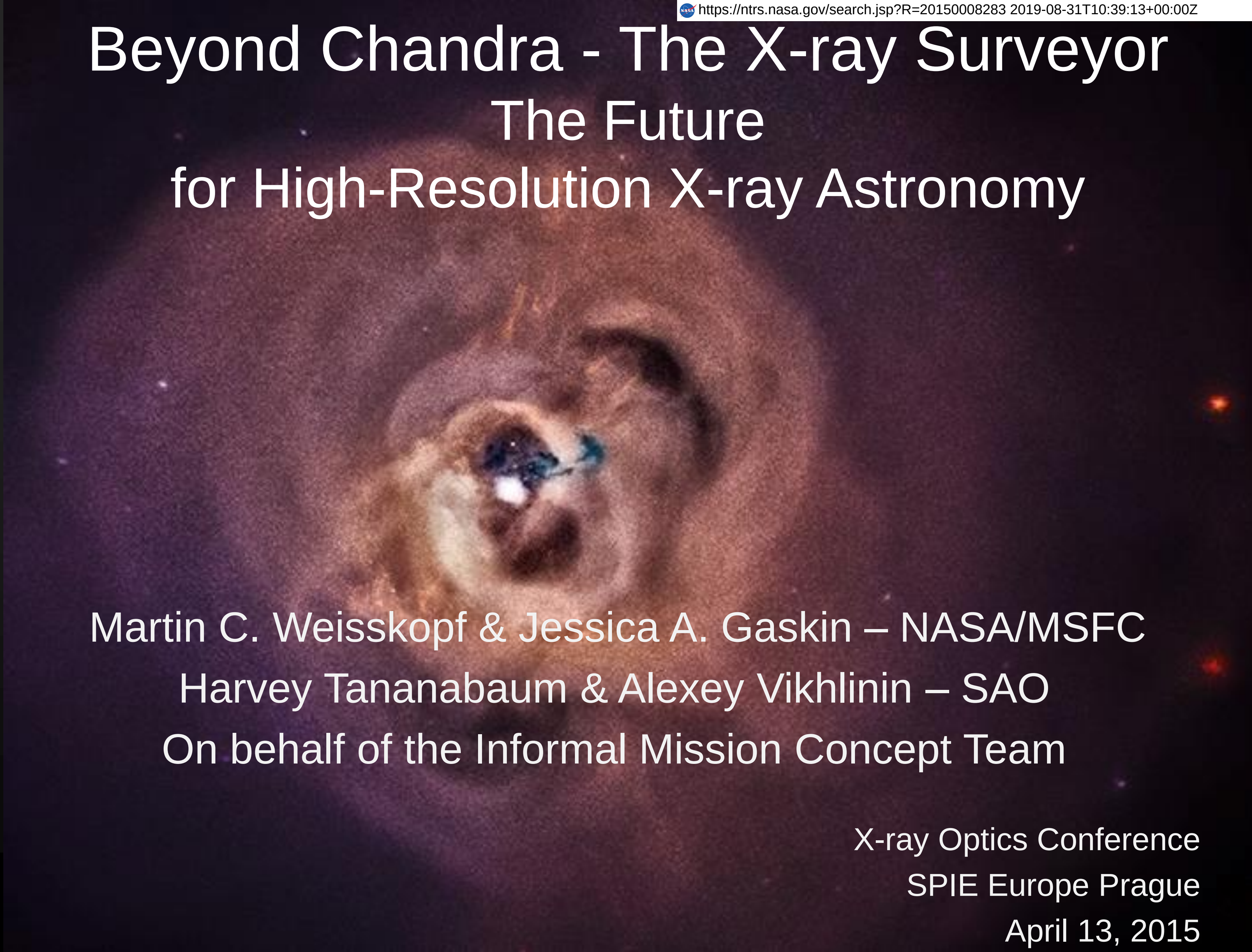


Beyond Chandra - The X-ray Surveyor
The Future
for High-Resolution X-ray Astronomy

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

X-ray Optics Conference
SPIE Europe Prague
April 13, 2015

Why we are Talking about the X-ray Surveyor

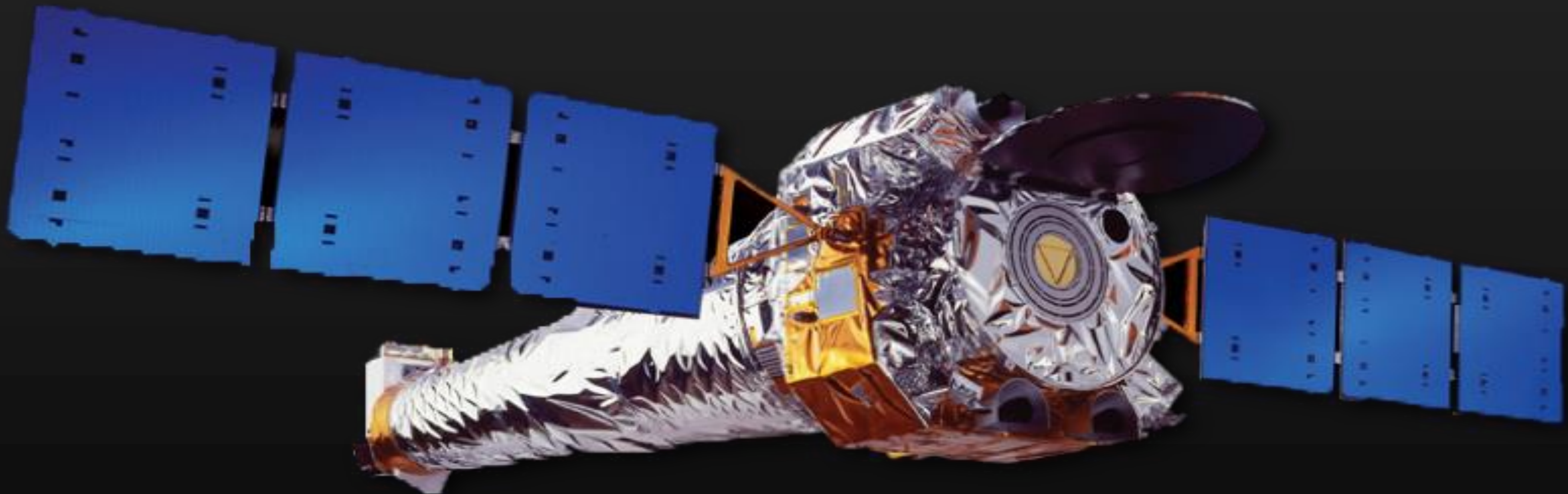
- NASA Astrophysics Division white paper: Planning for the 2020 Decadal Survey
  - Provided an Initial list of missions drawn from 2010 Decadal Survey and 2013 Astrophysics Roadmap that includes the X-ray Surveyor
  - Requested the three NASA Program Analysis Groups (PAGs) to coordinate community discussion 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

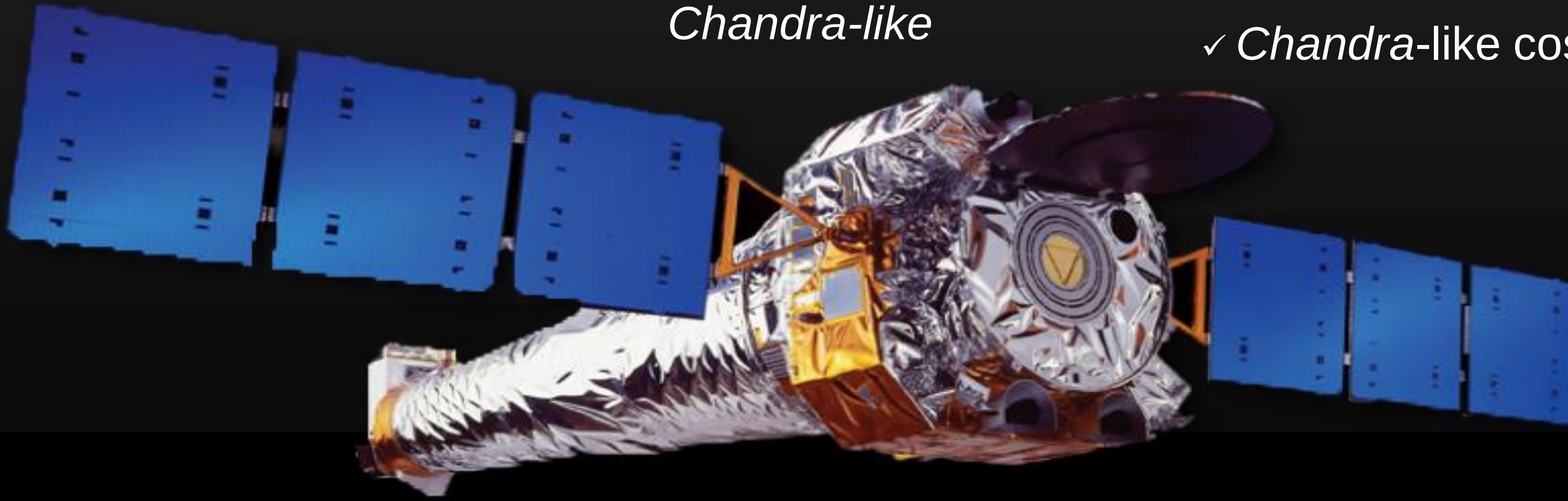
The Baseline X-ray Surveyor Concept is a Successor to *Chandra* that:

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

✓Incorporates relevant IXO+ development and *Chandra* heritage

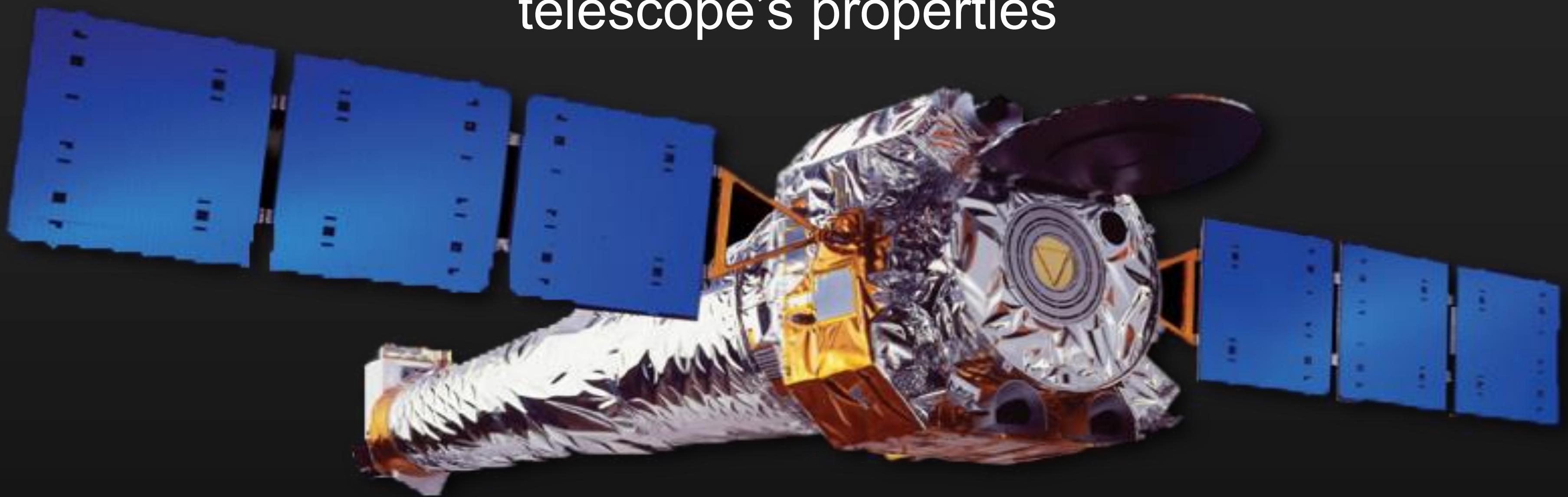
✓ Limits spacecraft requirements to *Chandra-like*

✓ *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

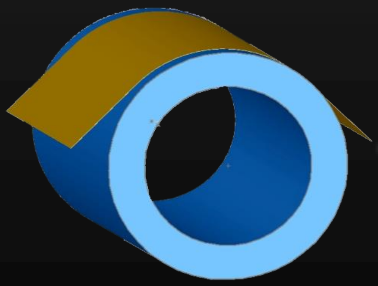
How will the Optics be Achieved?

- 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

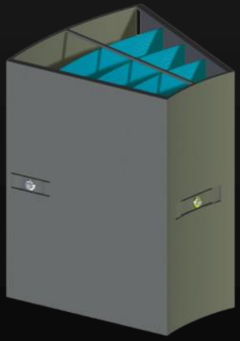
Build on NASA- Sponsored Heritage

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

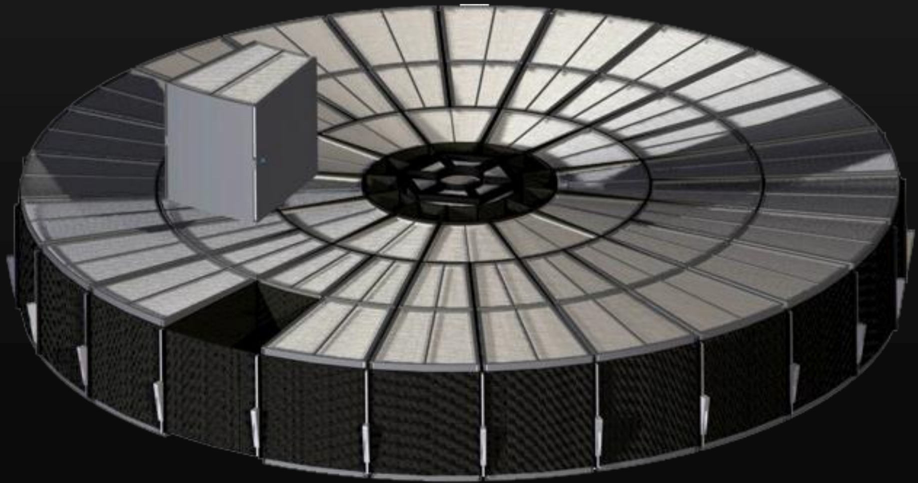
Fabrication



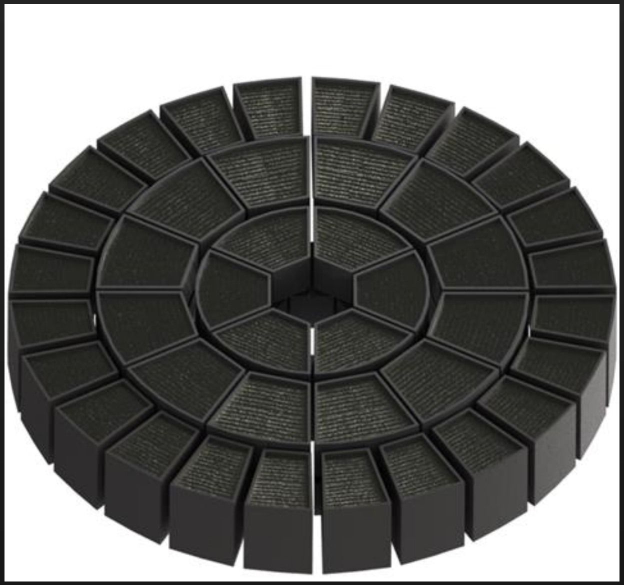
Alignment & Mounting

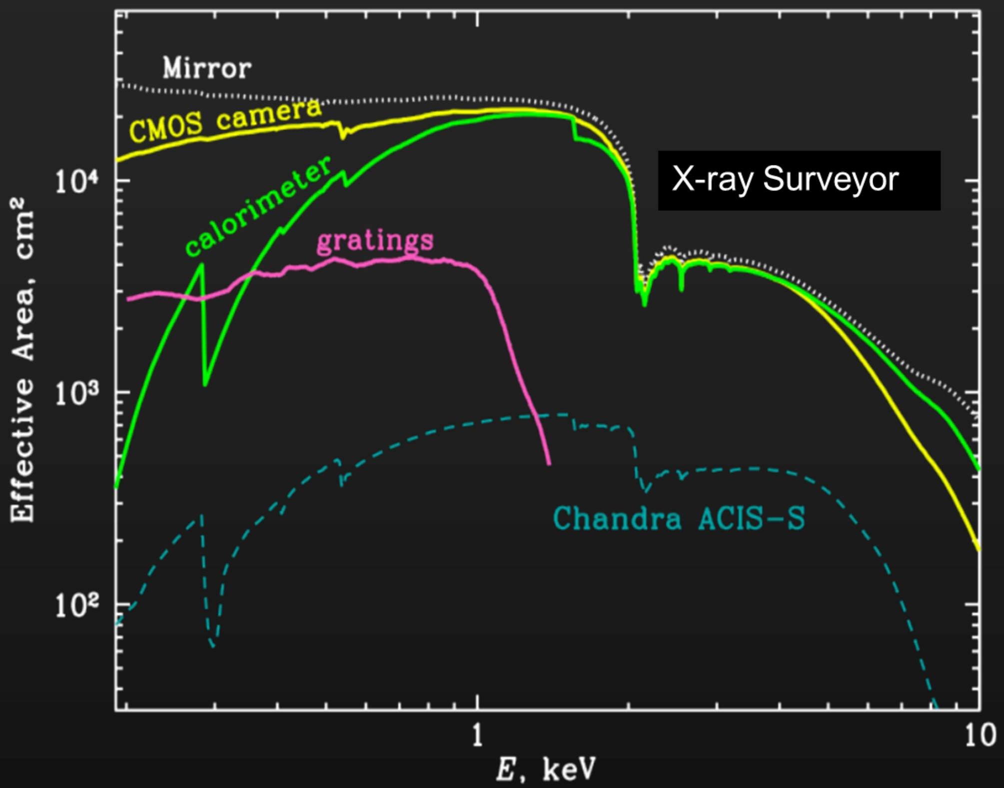


Integration



Surveyor Optics: Specifications & Performance

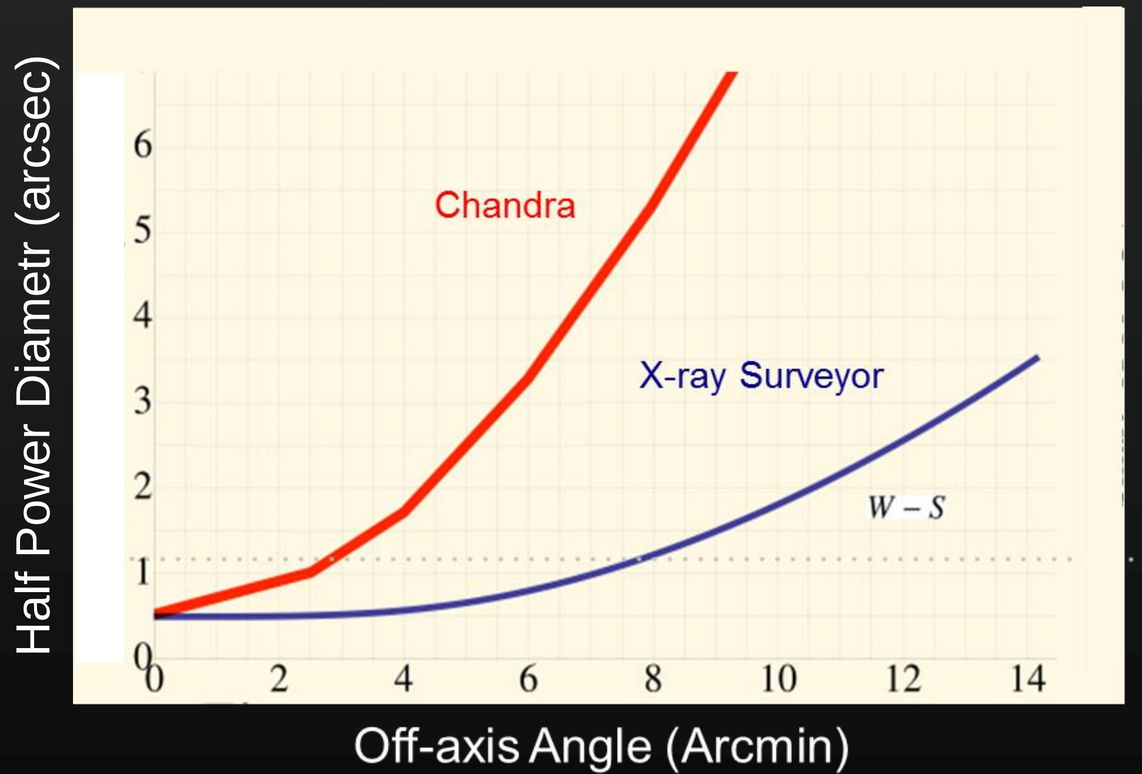




- 292 nested shells, 3m outer diameter, segmented design
- Wolter-Schwarzschild optical scheme
- 30 × more effective area than Chandra
- 4-Msec detection limits below 3×10^{-19} erg/s/cm^2 (0.5–2 keV)

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)

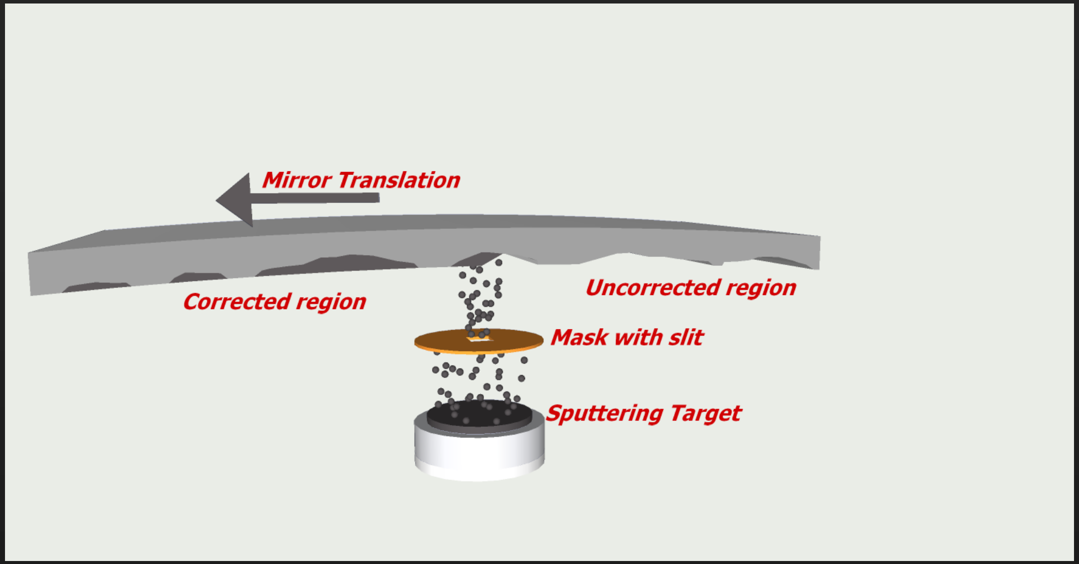
- Adjustable optics
  - Piezoelectric film on the back surface (SAO/PSU)
  - Magneto-restrictive film on the back surface (NW)

ALSO WATCH

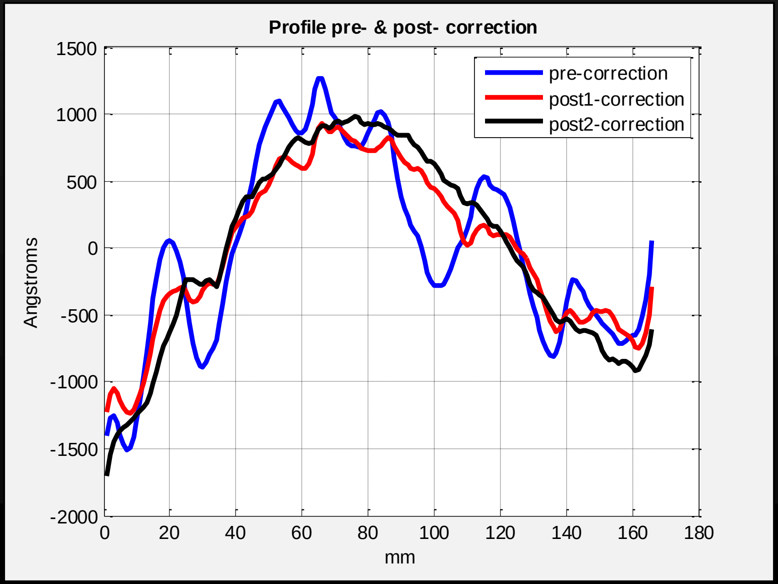
- Slicing and forming thin polished silicon (GSFC)

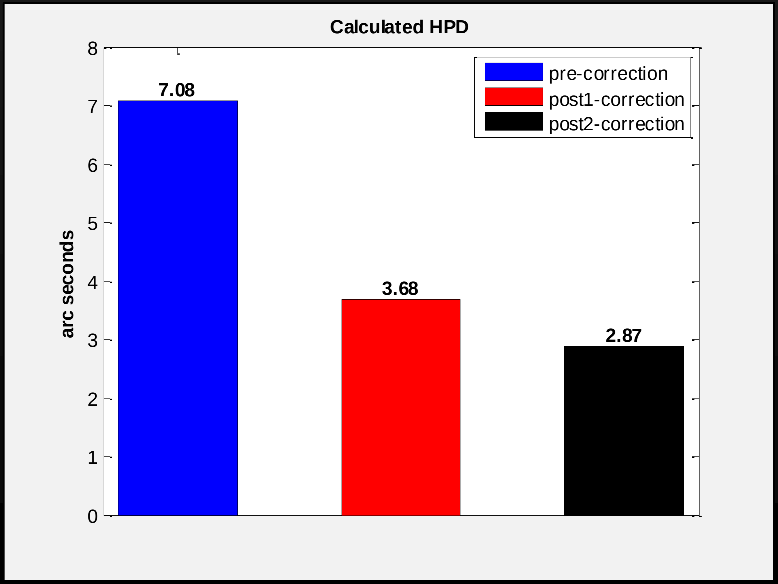
Final approach may well be a combination of the above

Differential Deposition (MSFC/RXO)



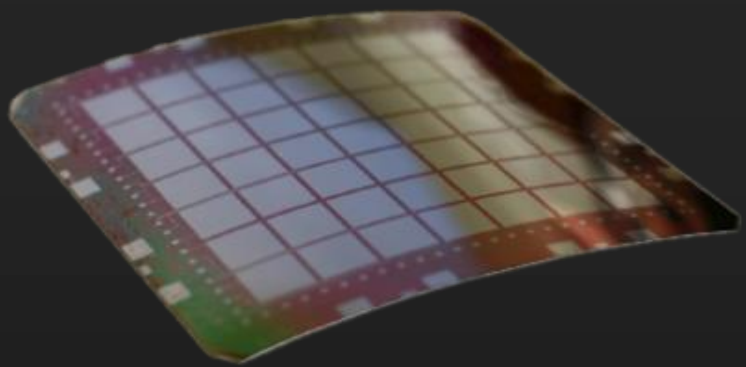
7.1″ to 2.9″ (HPD – 2 reflections) in two passes

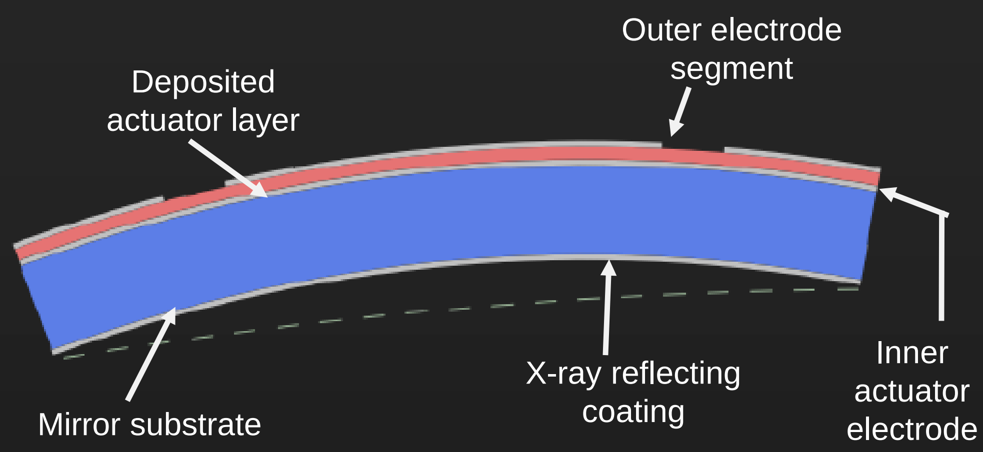




Status --- see next talk

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

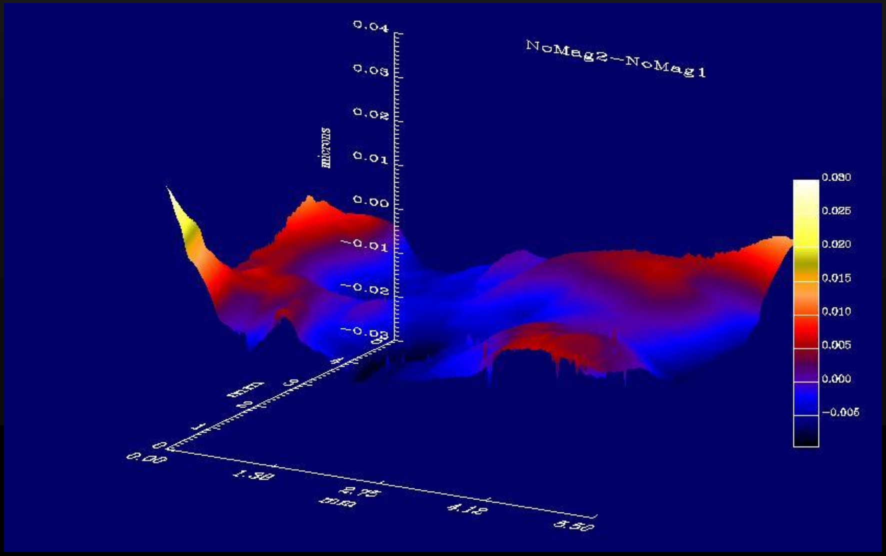
Adjustable Optics - Magnetostrictive (NW)

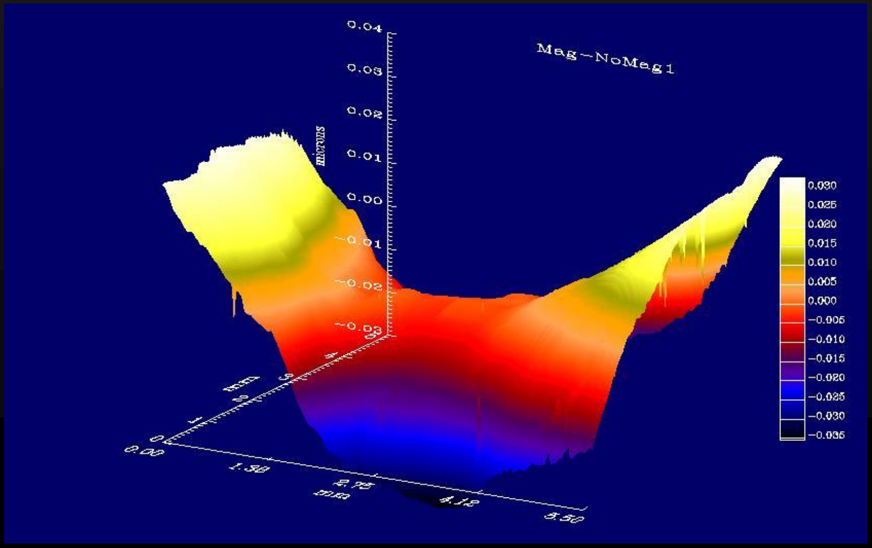
Magnetic smart material applied to NiCo, a magnetically hard substrate 5 mm x 20 mm x 100 μm, showed:

- 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

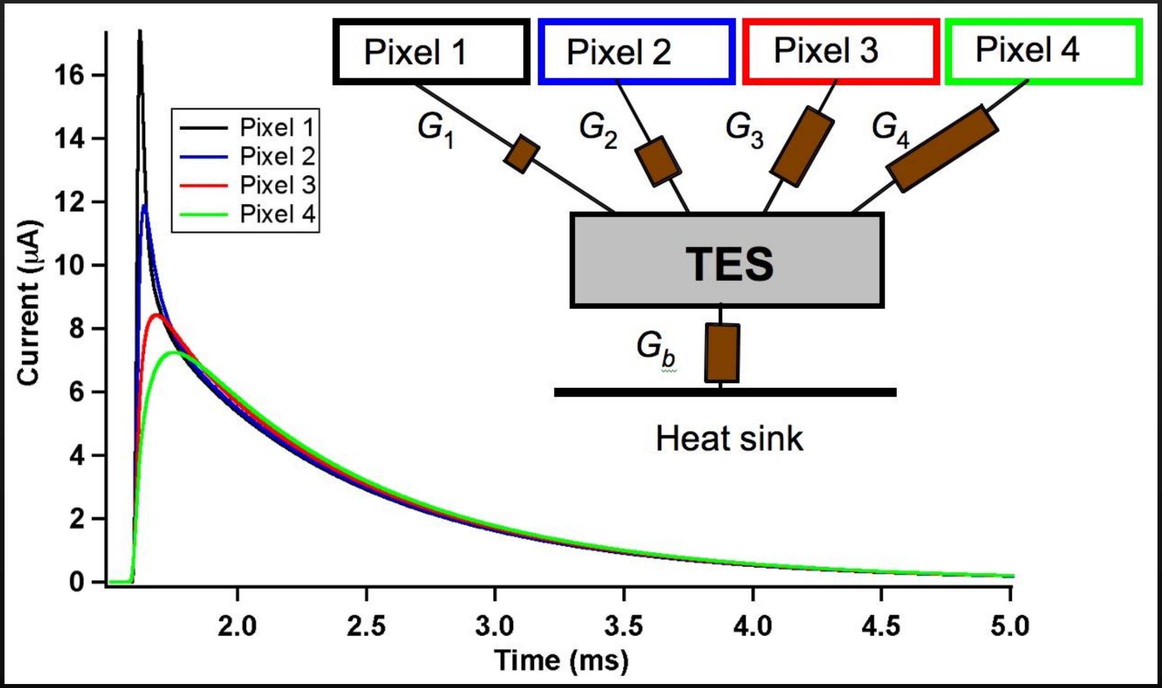




Microcalorimeter Imaging Spectrometer

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

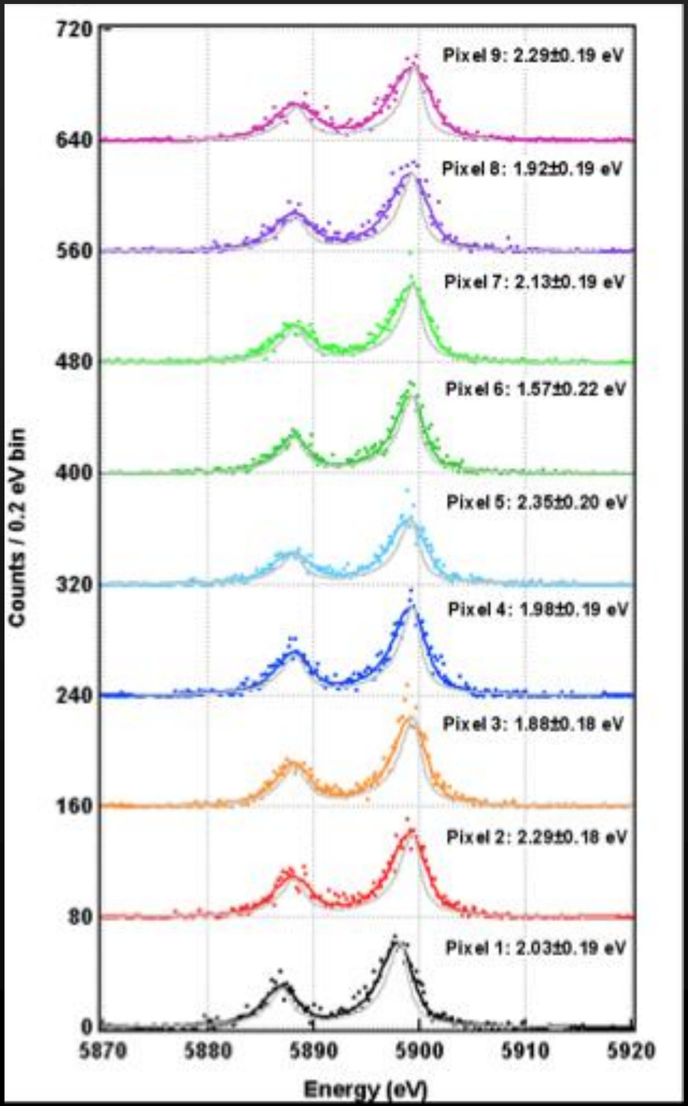
- Conceptual design by S. Bandler et al. (GSFC&NIST):
- Transition Edge Sensors with SQUID readout.
- Multiplexing is feasible via multiple absorbers per one TES (“Hydra”design)



Microcalorimeter Imaging Spectrometer

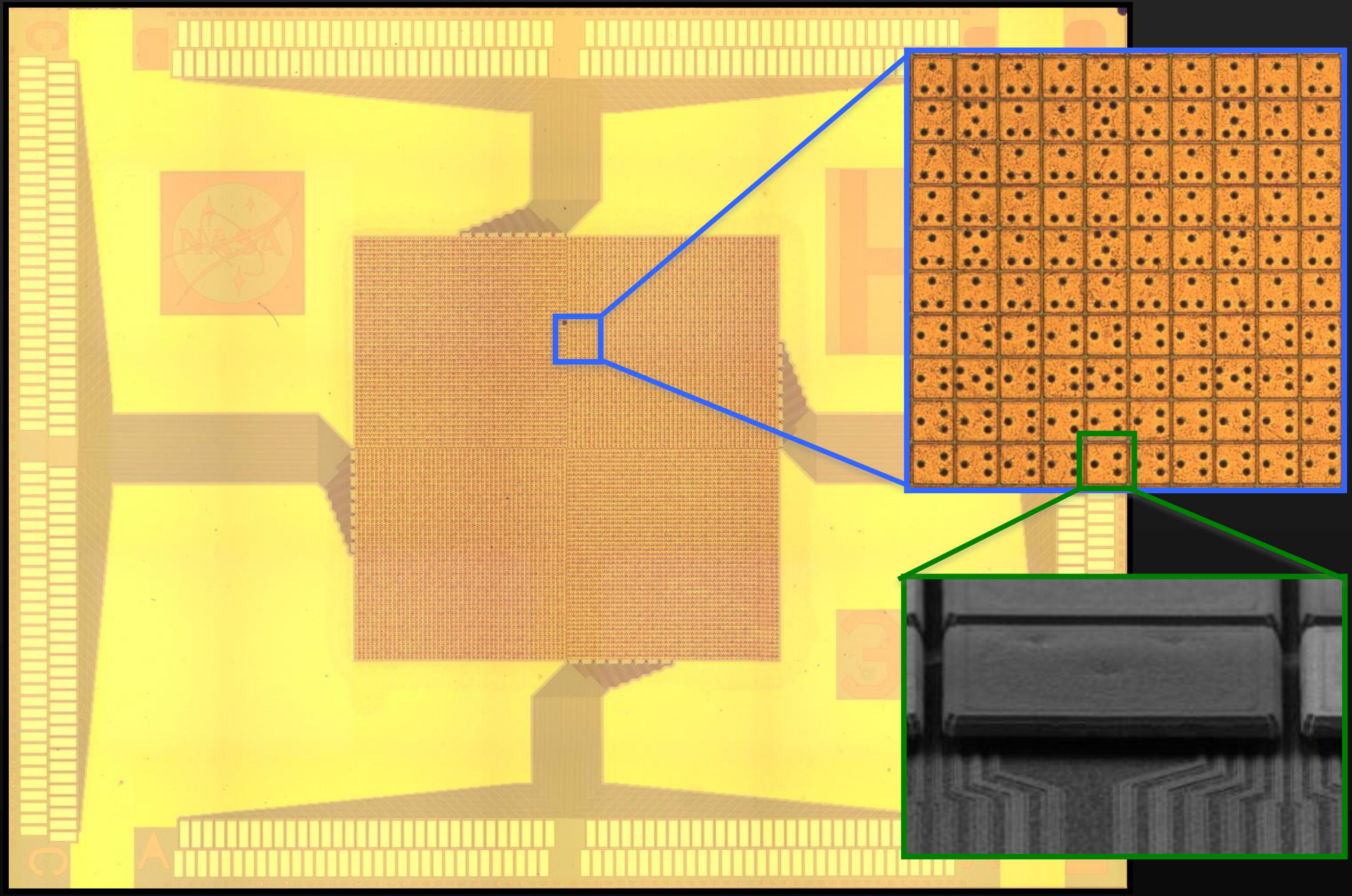
Energy Resolution (w 3 x 3 Hydra)

- 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

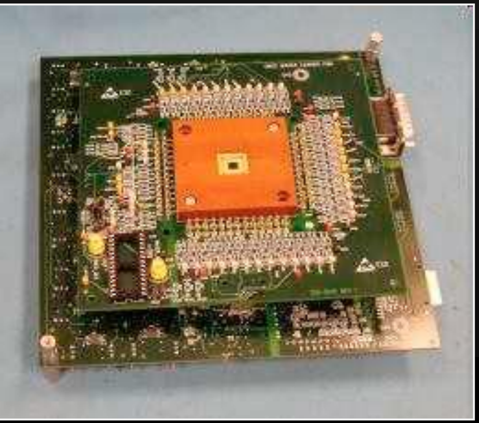


96 x 96 array - fully wired within array – absorbers on 75 μm pitch
- 32 x 32 array of 3x3 Hydras

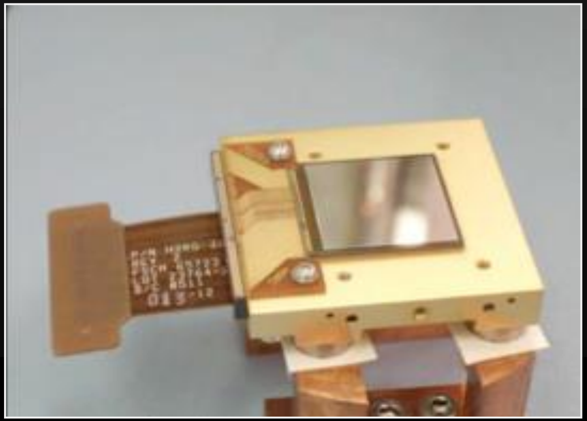
Active Pixel Sensor Imagers

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

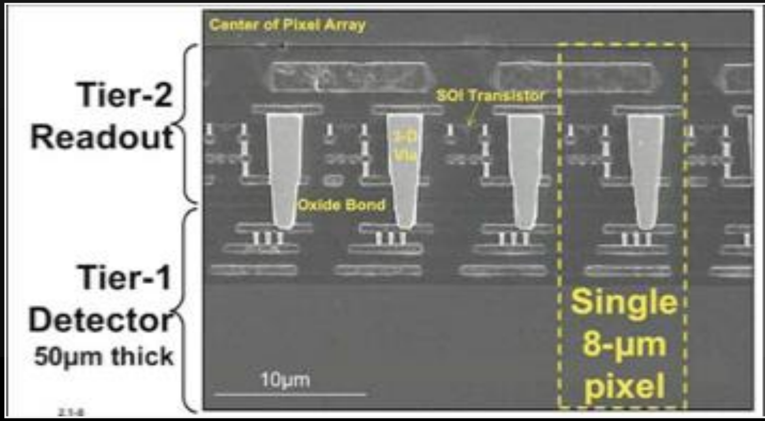
- *X-ray Surveyor needs*
  - 16 μm (= 0.33 arcsecond) pixel size or smaller
  - 4k × 4k array (22′ × 22′ FOV) or bigger
  - Goal of Fano-limited resolution: 33 eV @ 0.5 keV, 48 @ 1 & 120 @ 6
  - QE > 90% (0.3-6.0 keV)



SAO/Sarnoff



PSU/Teledyne

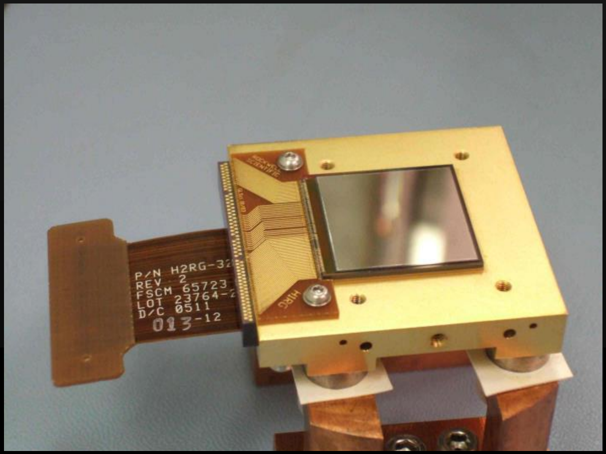


MIT/Lincoln Lab

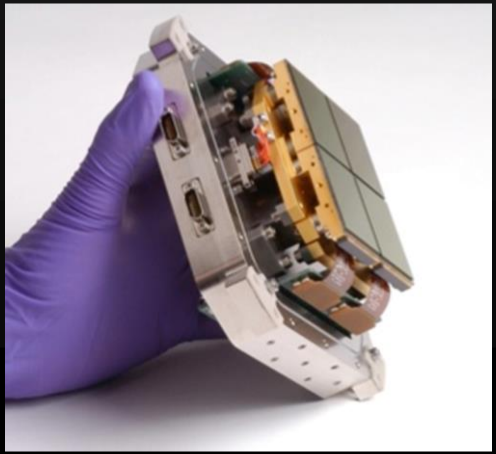
Active Pixel Sensor Imagers: PSU/Teledyne

- 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



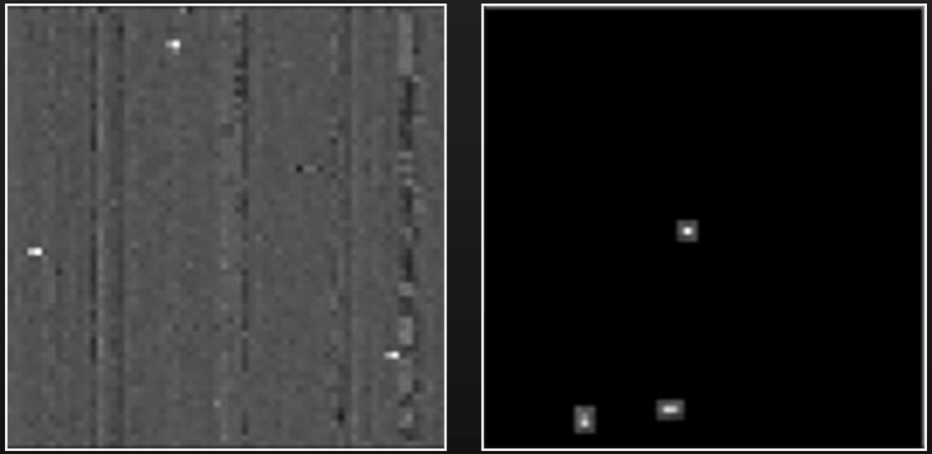
Teledyne detector mosaic



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



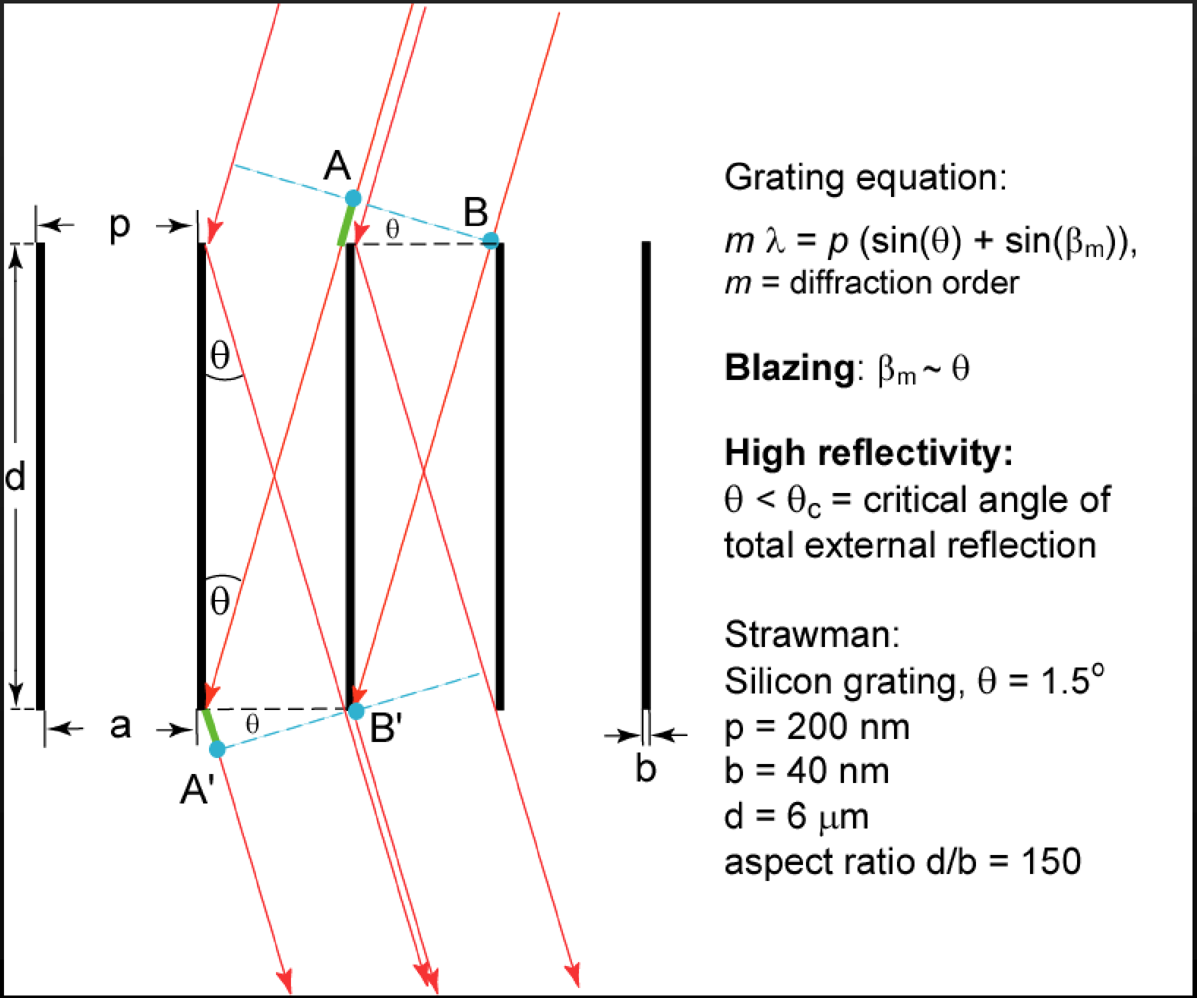
- Smaller pixels (<15 µm) are needed for X-ray Surveyor so PSU/Teledyne has completed an initial design of a Si hybrid CMOS detector with 15 µm pitch pixels, CTIA amplifiers, guide window, and in-pixel Correlative Double Sampling

Transmission Gratings

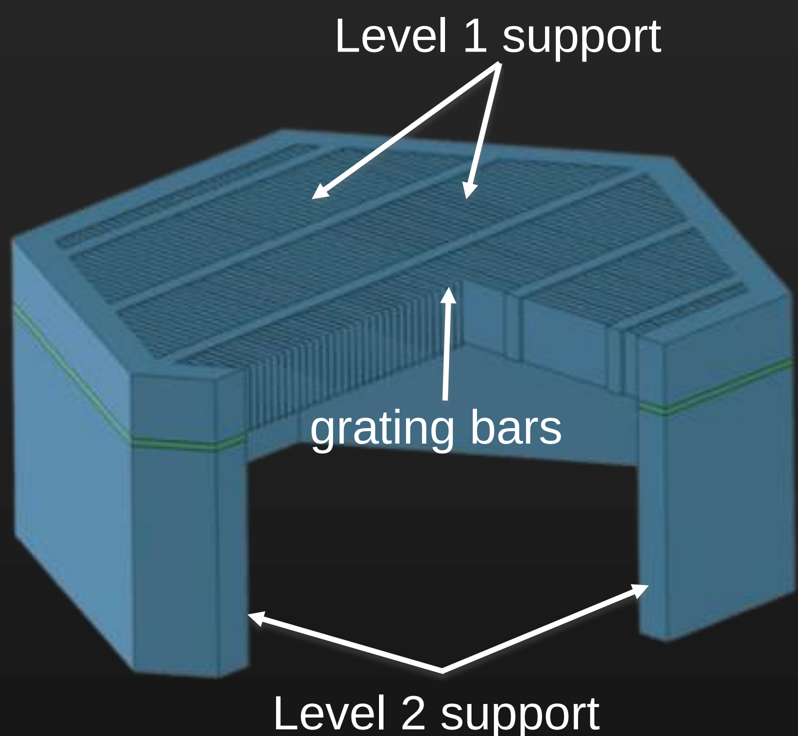
- Area = 4000 cm^2
- Resolving power = 5000
- Energy range 0.2 – 2.0 keV
- Critical Angle Transmission (CAT) Gratings (MIT)
- Blazed Off-Plane Reflection Gratings (Univ. of Iowa)

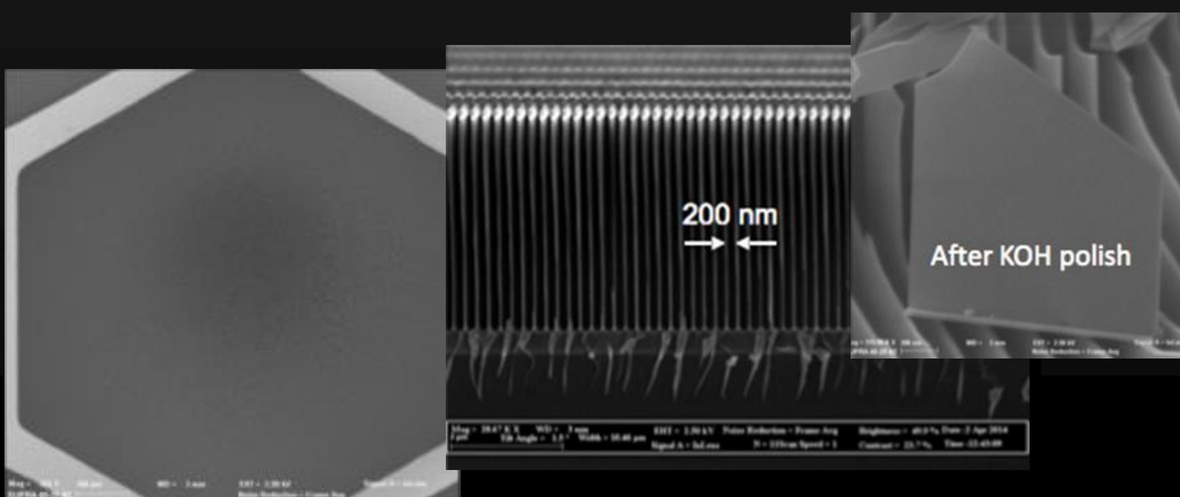
Critical Angle Transmission Grating: Principle

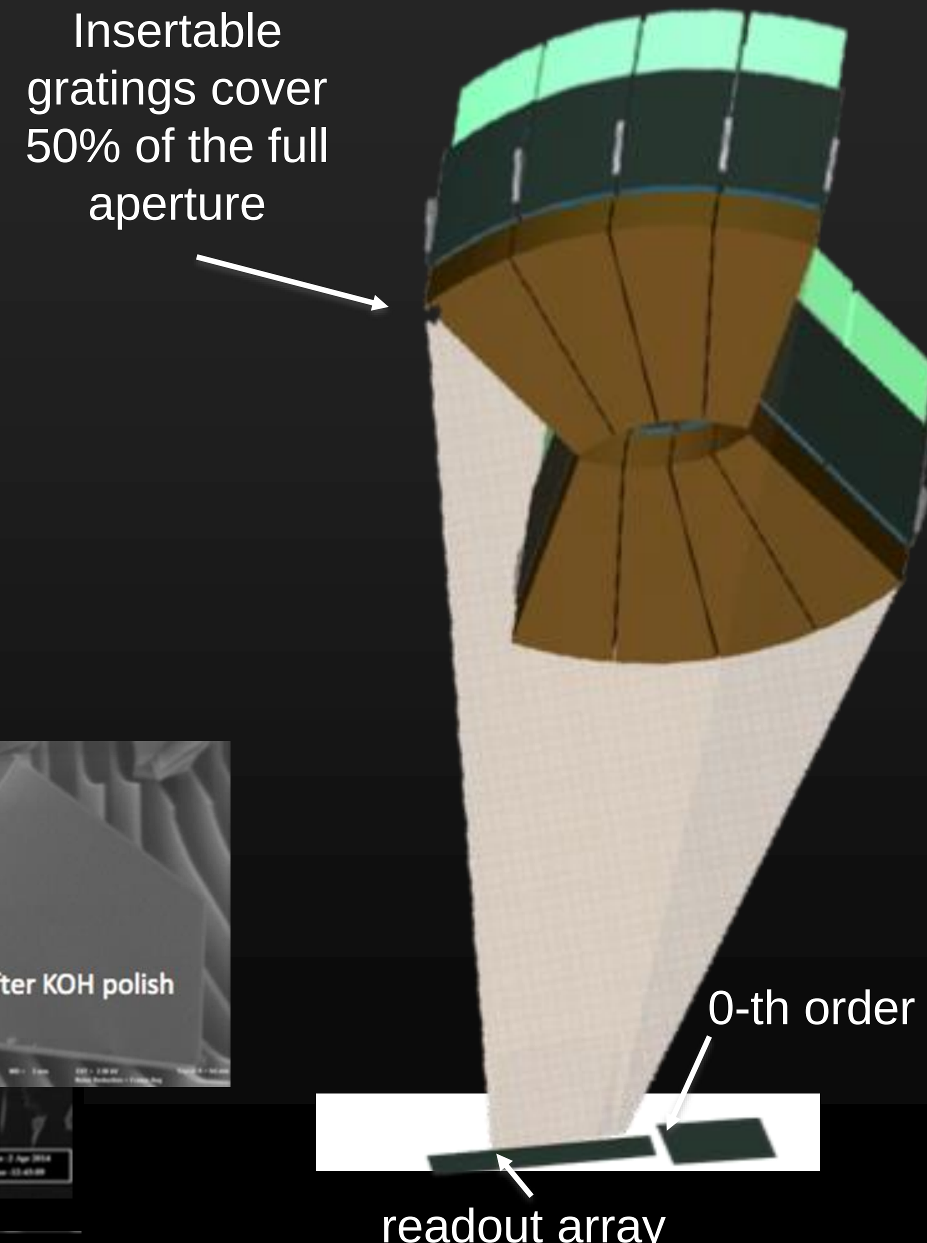
- Combines transmission and blazed grating
- Blazing achieved via reflection from sidewalls at graze angles below the critical angle
- High energy X-rays contribute to effective area at focus



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