The Constellation-X Hard X-ray Telescope: Technology Development Status and Plans

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For the HXT Team

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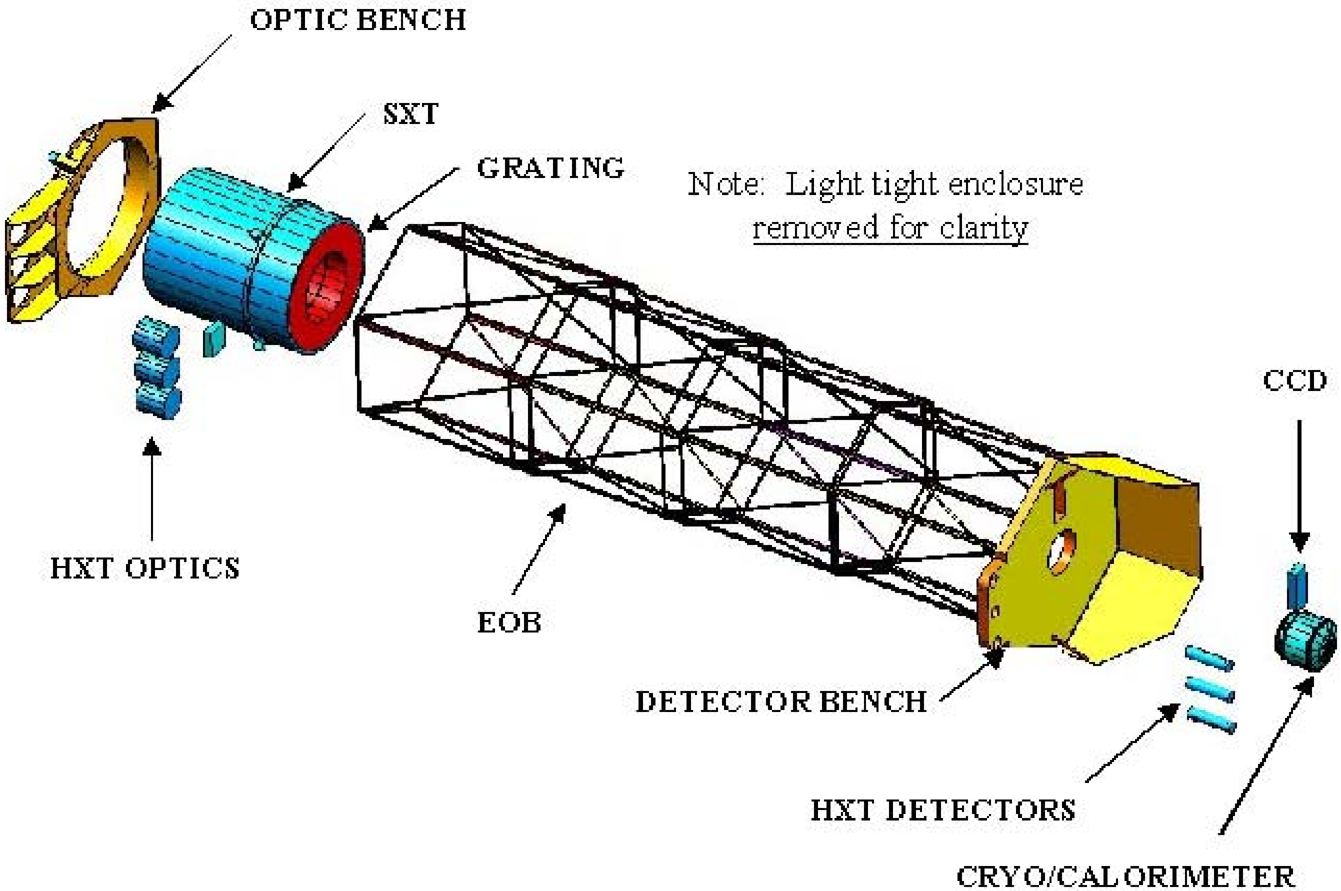
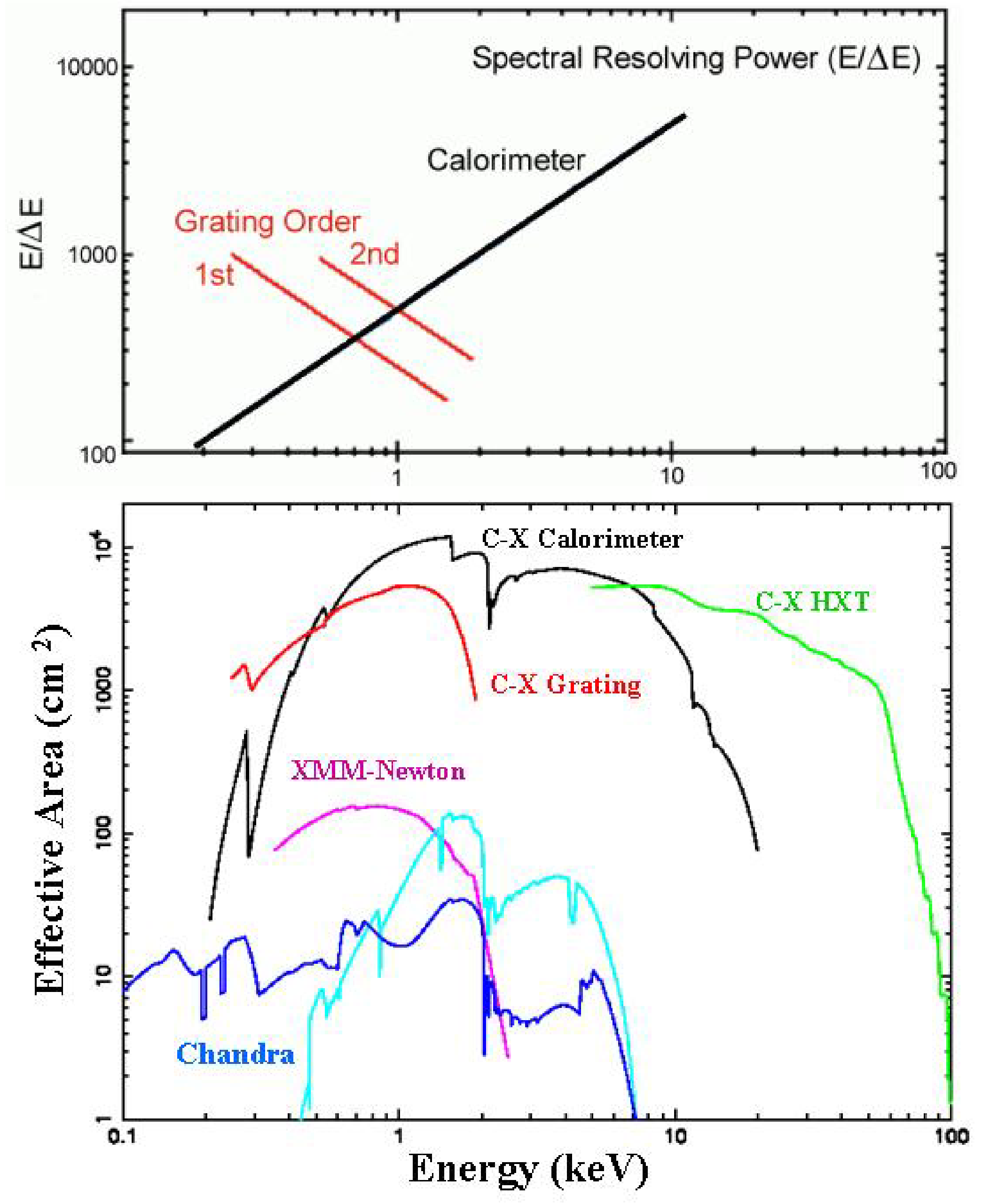
ORS



Exploded View (Top/Side) - IM



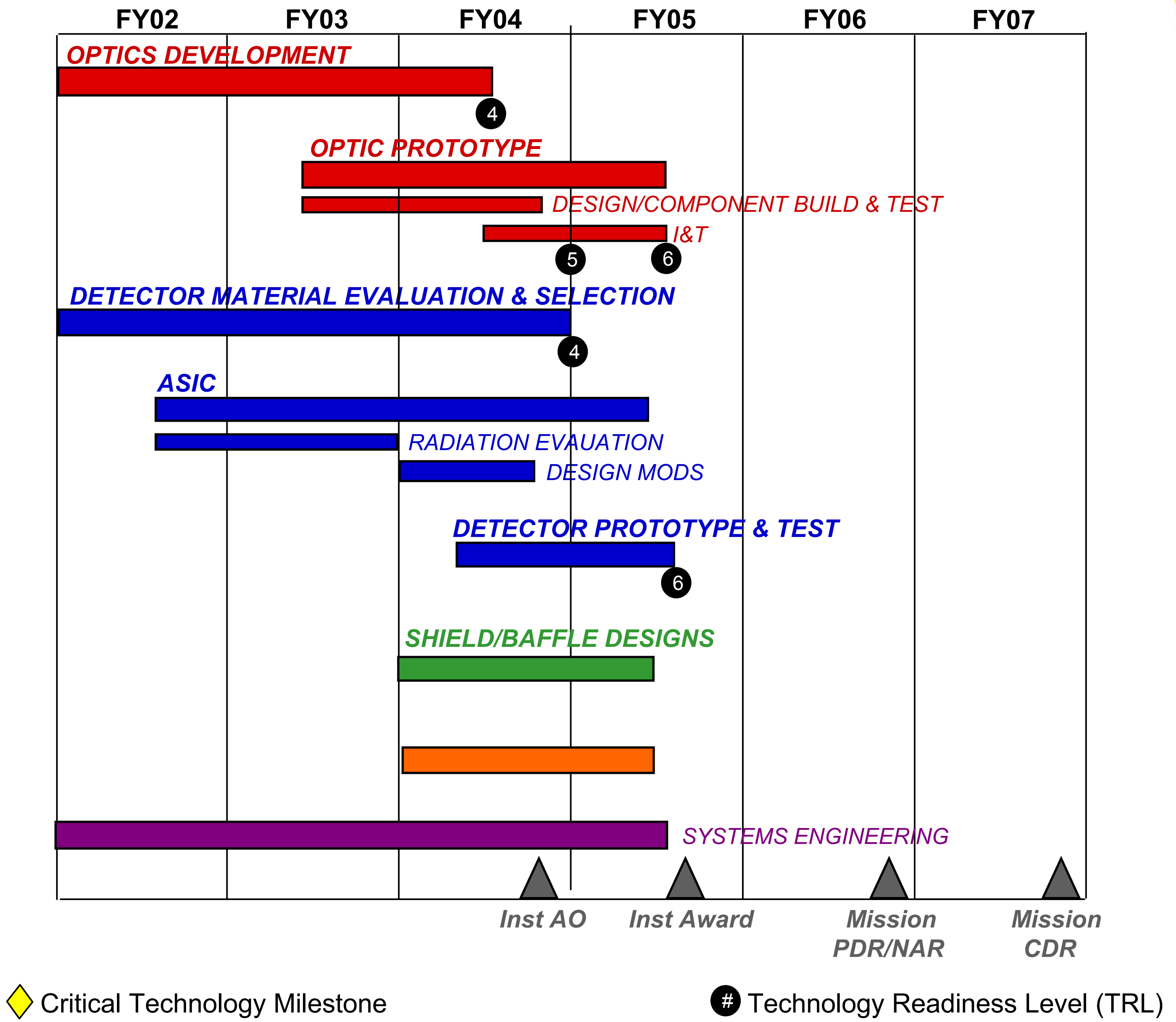
Spectral Resolving Power (E/ΔE)
E/ΔE
10000
1000
100
Calorimeter
Grating Order
1st
2nd
1
10
100
C-X Calorimeter
C-X HXT
C-X Grating
XMM-Newton
Chandra
Effective Area (cm 2)
10⁴
1000
100
10
1
0.1
1
10
100
Energy (keV)

Con-X HXT Requirements

Baseline HXT Requirements	
Effective Area	$\geq$ 1500 cm^2 (5 - 40 keV)
Signal/Background	$\geq$ 1 for $T_{obs} > 2 \times 10^4$ s
FOV	$\geq$ 8 arcmin (5 - 40 keV)
Angular resolution	$\leq$ 1 arcmin HPD
$\Delta E/E$	$\leq$ 20% (5 - 30 keV)
Desirable Performance Enhancements	
Signal/Background	$\geq$ 1 for $T_{obs} > 2 \times 10^4$ s
Effective Area/	$\geq$ 1500 cm^2 (5 - 40 keV)
Bandpass	extend to 1 keV
Angular resolution	30" HPD
$\Delta E/E$	$\leq$ 5% at 40 keV
Mechanical Envelope	
Total Mass/Satellite	$\leq$ 250 kg
Geometric Aperture	< 0.75 m^2
Focal Length	10 meters

- Match spectroscopic sensitivity of SXT for high-energy continuum observations

- Map non-thermal emission in extended sources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FY03
FY04
FY05
FY06
FY07
OPTICS DEVELOPMENT
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OPTIC PROTOTYPE
DESIGN/COMPONENT BUILD & TEST
I&T
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6
DETECTOR MATERIAL EVALUATION & SELECTION
4
ASIC
RADIATION EVAUATION
DESIGN MODS
DETECTOR PROTOTYPE & TEST
6
SHIELD/BAFFLE DESIGNS
SYSTEMS ENGINEERING
Inst AO
Inst Award
Mission PDR/NAR
Mission CDR
Critical Technology Milestone
Technology Readiness Level (TRL)

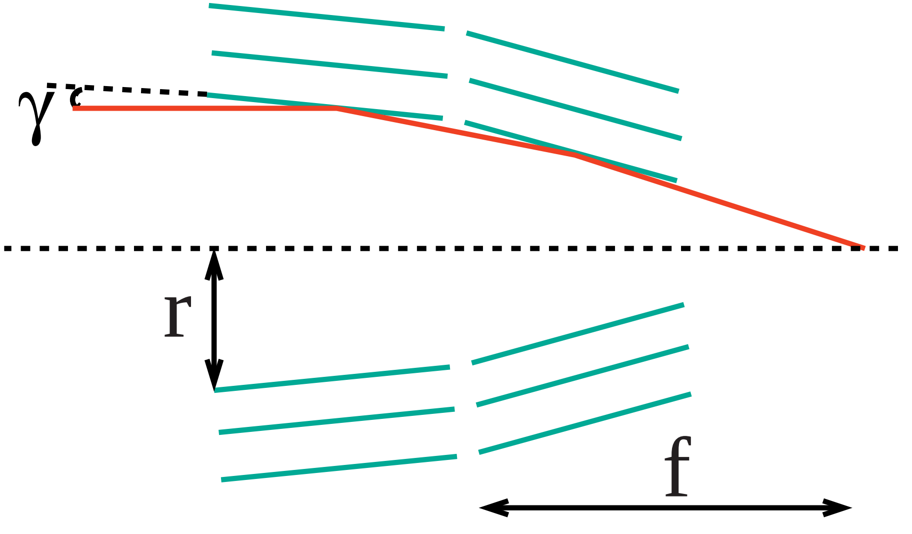
Hard X-ray Optics

X-ray optics are based on grazing incidence reflection

$$\mathbf{n = 1 - \delta - i\beta} \qquad \delta \sim 10^{-3}$$

Wolter-I or conical-approximation geometry most widely used in astronomical X-ray telescopes

good imaging properties over reasonable FOV



γ (graze angle) = 1/4 (r/f)

Wolter I mirror geometry

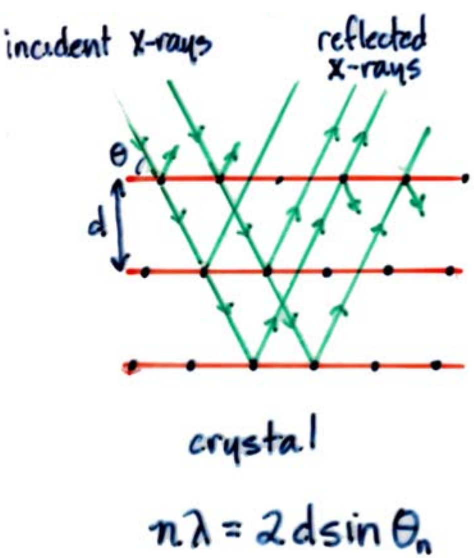
Graded Multilayer Coatings

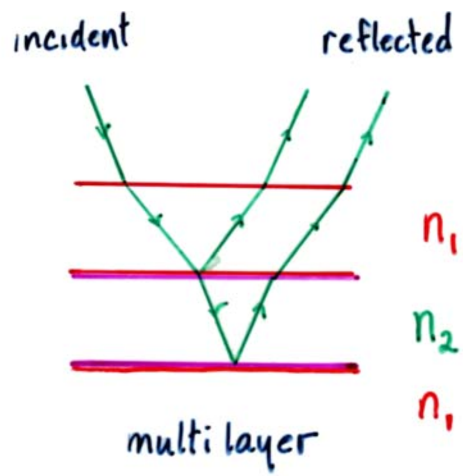
Graded multilayers operate on the principle of Bragg reflection

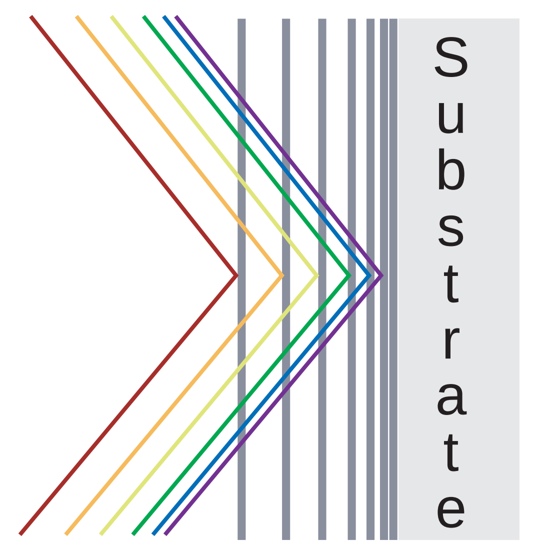
alternating layers of low and high index of refraction

$n\lambda = 2d \sin\theta$ – d = bilayer thickness

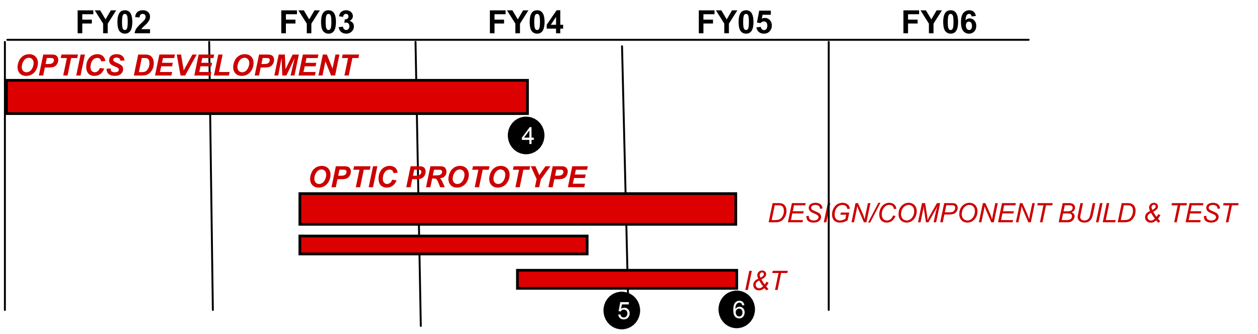
Wide range of bilayer thickness provides broadband reflectance







Optics



Development:

Develop segmented formed glass and Ni replica optics in parallel until mid FY03. Demonstrate critical technical steps on single or small prototype optics

Select glass or Ni for full prototype development – mid FY03

Prototype

Fabricate prototype capable of demonstrating performance (for full range of radii), mechanical, and thermal properties.

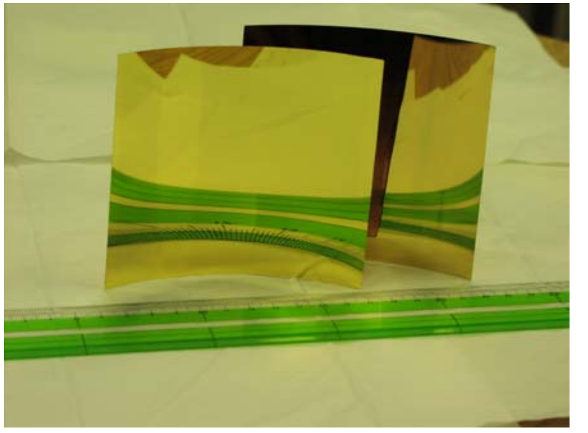
Test in relevant environment.

Mirror Substrates

Segmented shells:

(Columbia,DSRI,GSFC,LLNL, CIT)

- Thermally-formed glass microsheet with epoxy replication
- Direct ml deposition or replication
- segments (10/shell) assembled into full optic



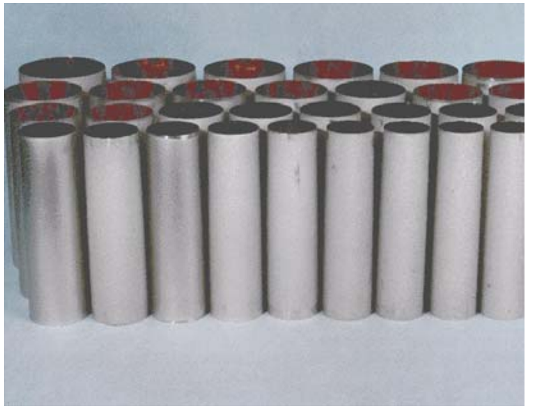
Replicated formed glass

Integral-replica shells:

(SAO, Brera, MSFC)

- Thin (0.1 mm) replicated shells in full-figure of revolution
- Multilayers deposited on mandrel and replicated onto shell interior

Why develop two options: Neither has demonstrated required performance (in an integrated optic). May exceed resolution goal and/or reduce mass compared to the requirement



SAX replica shells

Typical Designs

Telescope		
focal length	10 meters	
# satellites	4	
mirrors/satellite	3	
Multilayer		
material	W/Si	
minimum period	20 Angstroms	
max. # layers	500	
Optics:	**glass**	**nickel**
minimum radius	3 cm	6 cm
maximum radius	20 cm	20 cm
shell length	25 cm	40 cm
shell thickness	200 µm	100 µm
number of shells	149	82

Segmented Glass Optics

F. Christensen (DSRI), W. Craig (LLNL), C. Hailey (Columbia), R. Petre, W. Zhang (GSFC)

We are combining a precision mounting technique and newly developed replicated formed glass substrates

Formed glass optics and precision mounting technique developed for the HEFT balloon payload. Glass is formed, multilayer coated, and mounted. The angular resolution is currently limited by the glass figure.

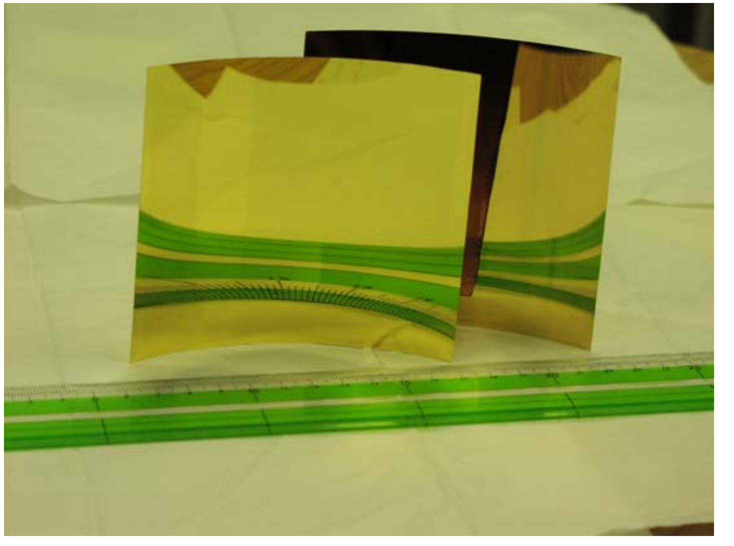
GSFC has developed formed glass with an epoxy replicated surface, greatly improving optic figure for similarly-sized segments.

The Con-X effort is supporting an effort to combine these with goal of significantly improving angular resolution – with a target of 30”

Segmented Glass Optics

Thin (200 – 300 μm) glass microsheet segmented into (typically) five azimuthal segments and two along the optical axis.

- Glass slumped over a forming mandrel in an oven.
- Epoxy replication reproduces the surface of a gold-coated mandrel.
- Multilayers can either be deposited directly on the replicated glass, or can be deposited on the mandrel and pulled off.

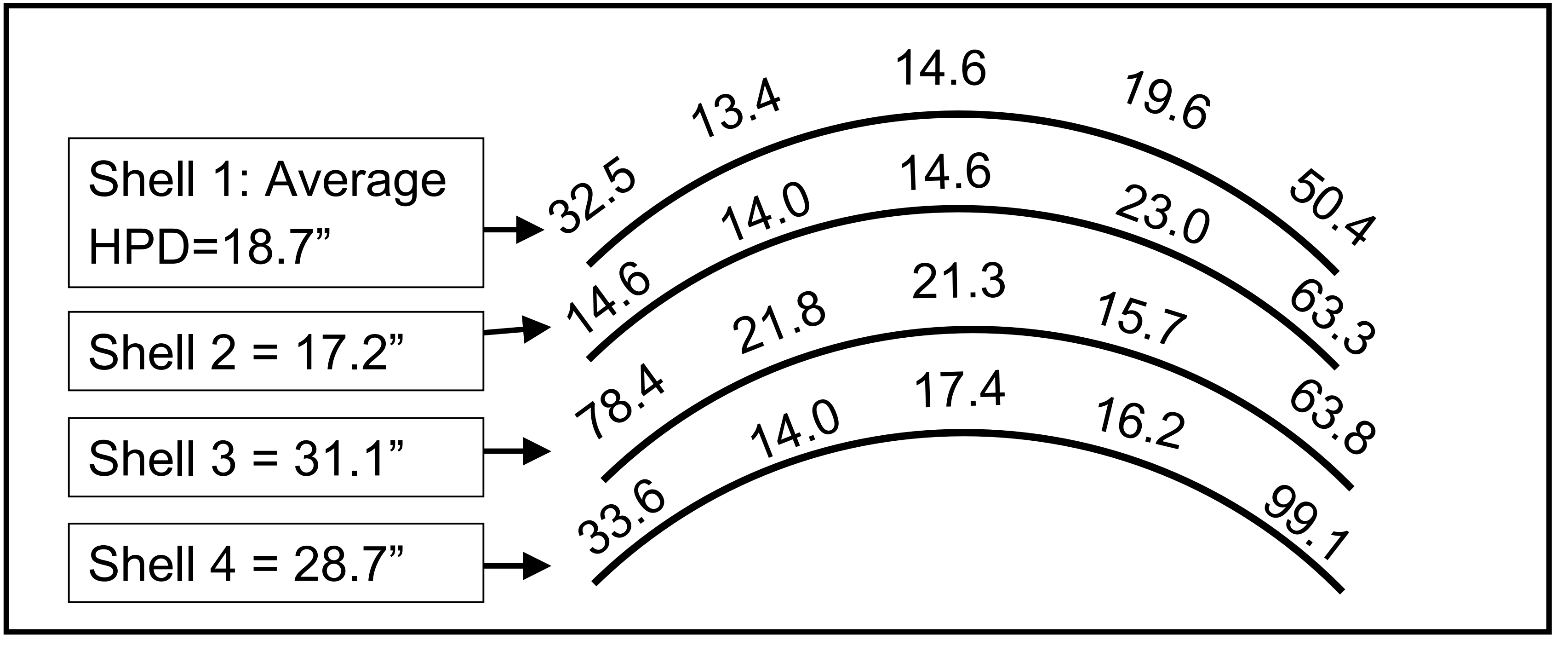


The segments are replicated as cones (conical approximation contributes 11’’

Segmented Glass Optics

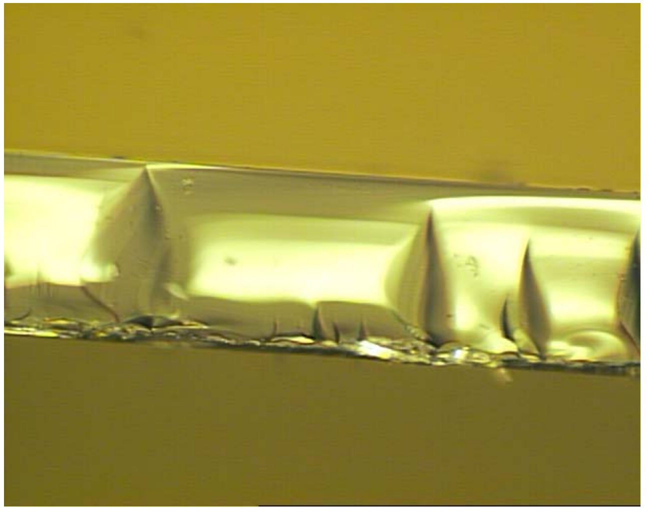
GSFC epoxy replicated glass shells show excellent performance

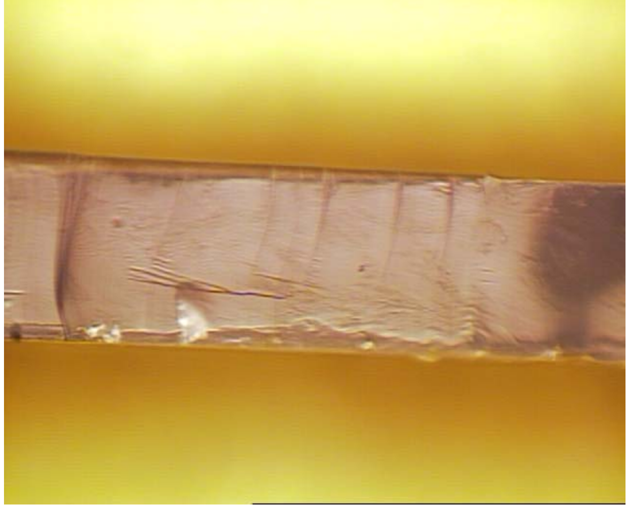
- Axial interferometric scans, at 5 azimuthal positions, on the 4 trial shells show performance exceeding HXT goals
  - better performance at center; all half power diameter numbers, in arcseconds, are for two-reflections

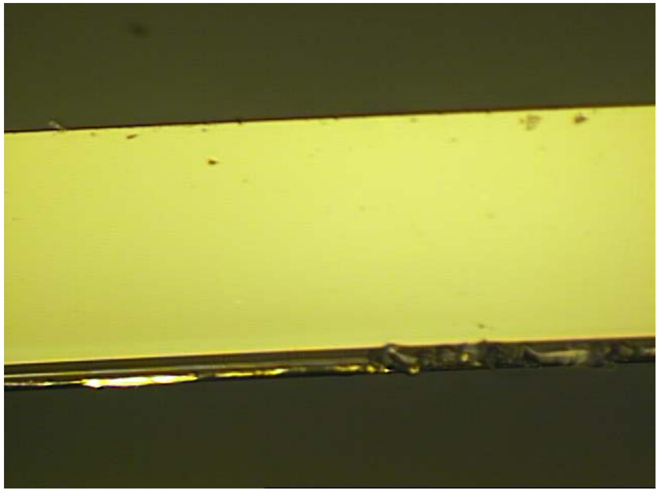


Segmented Glass Optics

Glass cutting advances reduce potential fracture sites







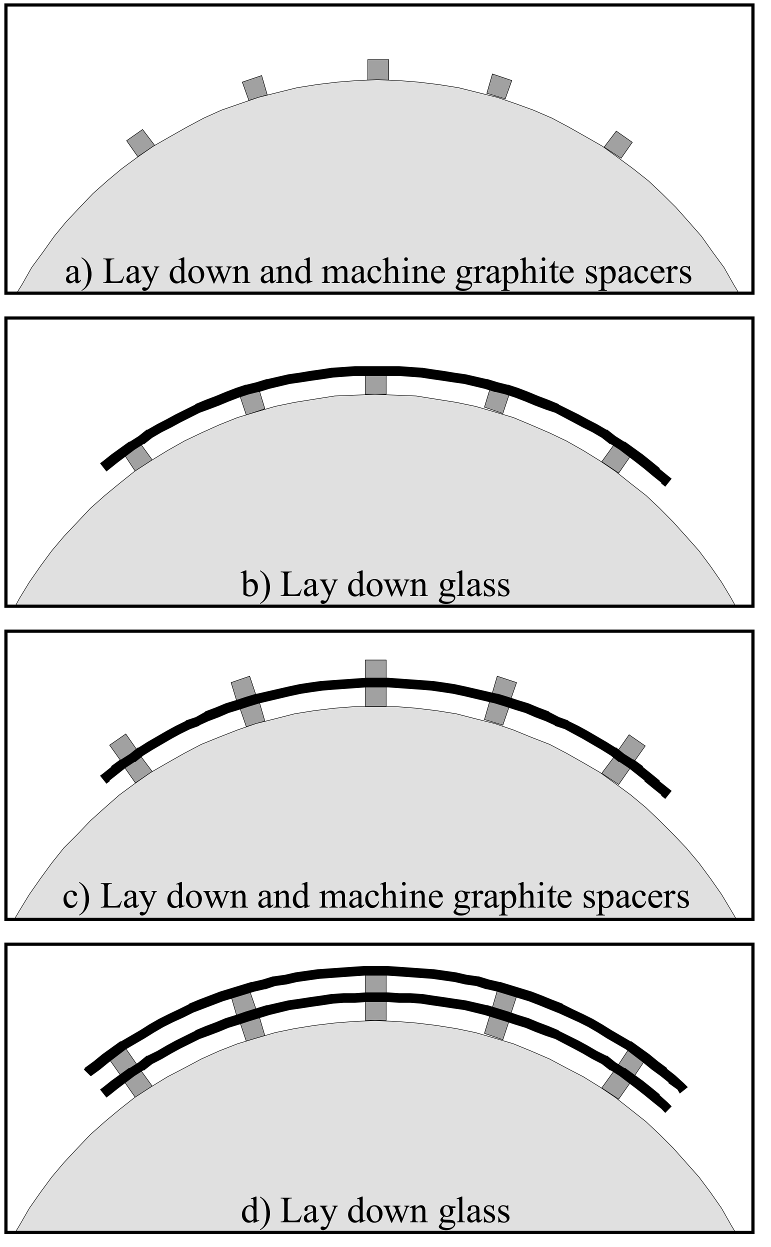
Upper left:
score with a carbide scriber and break

Upper right:
cut with a CO_2 laser

Lower left:
cut with the GSFC technique

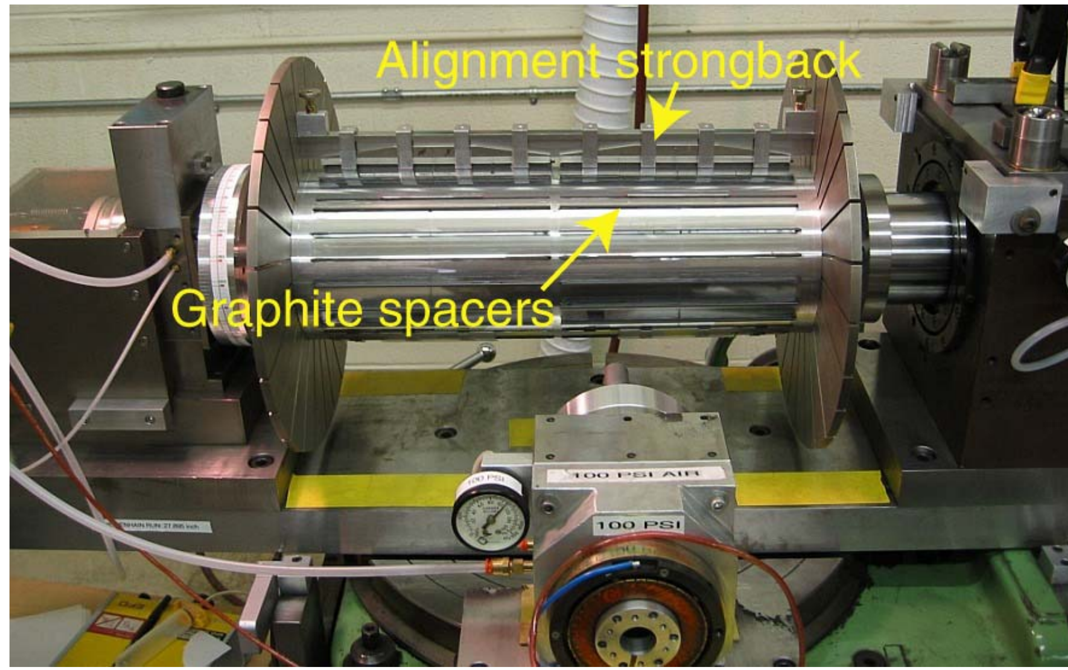
Segmented Glass Optics

Newly-developed over-constrained mounting technique has demonstrated the ability to mount shells with precision corresponding to 20''.



Segmented Glass Optics

Assembly machine is now operational at Colorado Precision Products



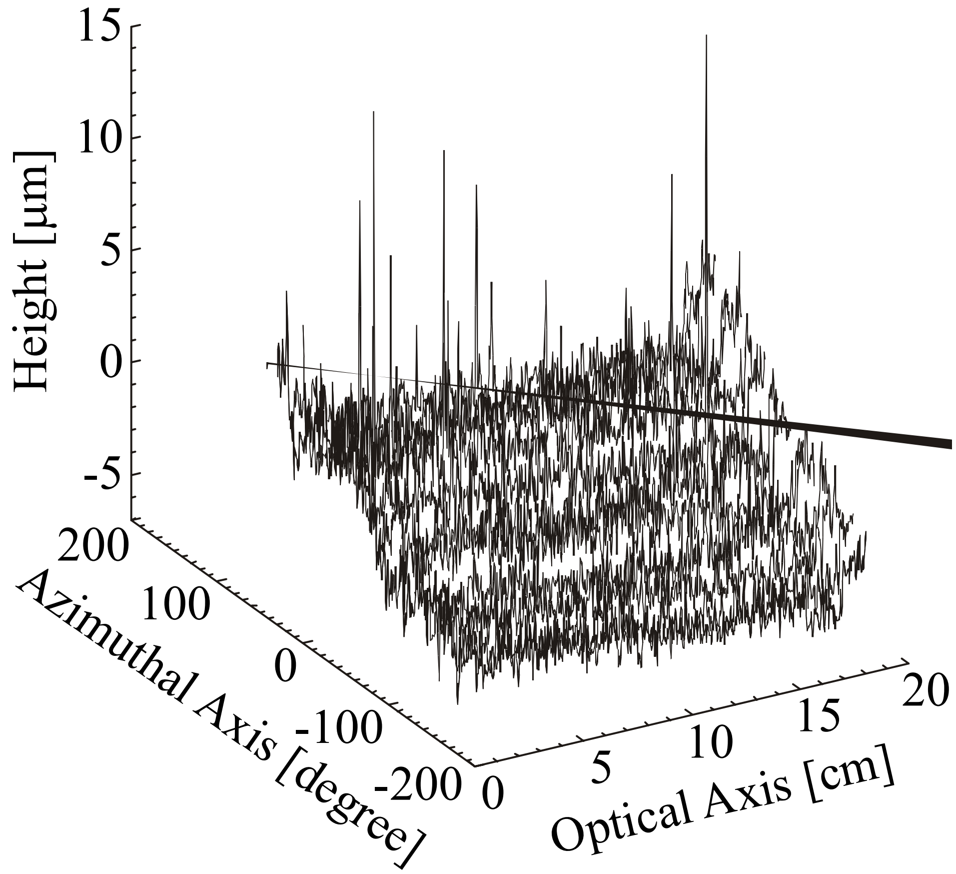
Assembly machine uses air bearing spindles and Moore tables to achieve sub-micron precision.

Glass prototype shells being assembled on the machine at CPPI

Segmented Glass Optics

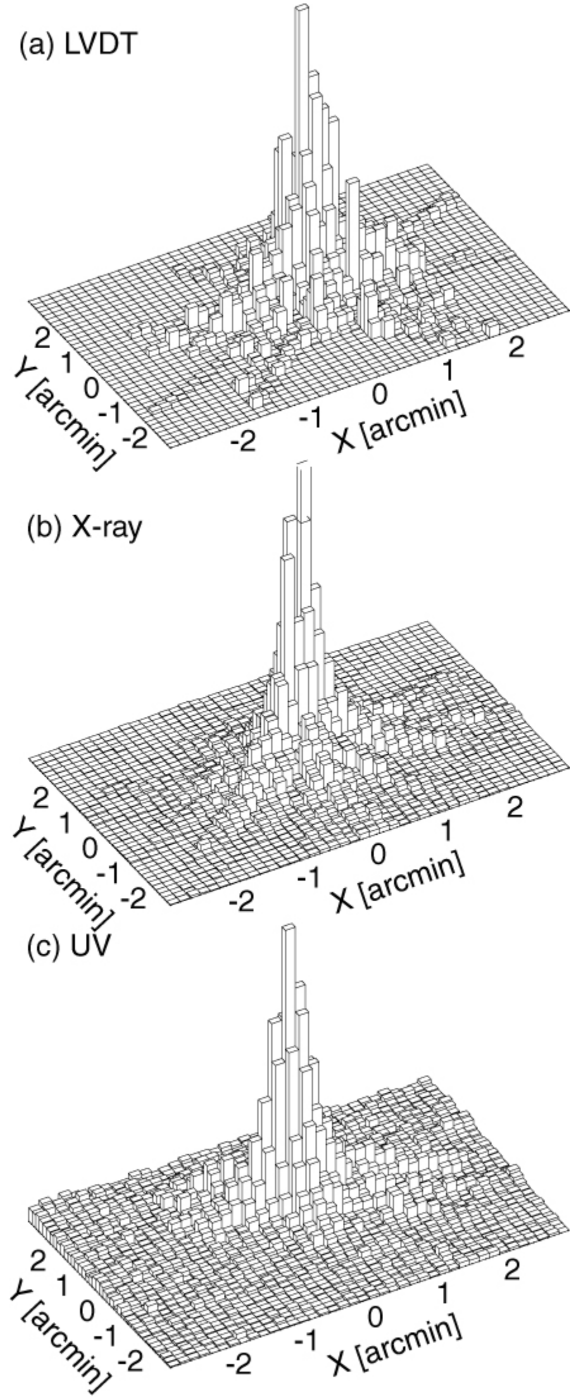
Assembly machine now produces machined spacers at exceeding the required precision.

Axial LVDT measurements are plotted with respect to their axial position on the optic for an entire complement of machined spacers. The machined spacers have a high frequency peak to valley roughness of about 1.5 mm. The tool wear of ~0.5 mm per spacer, evident as a function of azimuth in the plot, is compensated for in the machining process.



Graphite spacers are machined to better than 3” slope error

Measurements of HEFT prototype demonstrate agreement between different metrology approaches.



LVDT scanning measurements made during fabrication

X-ray pencil beam scans made at DSRI

Full-illumination at Colorado UV facility

Segmented Glass Optics

Projected HPD performance:

shell figure	20’’
mounting/align	<10”
conic approximatin	11’’

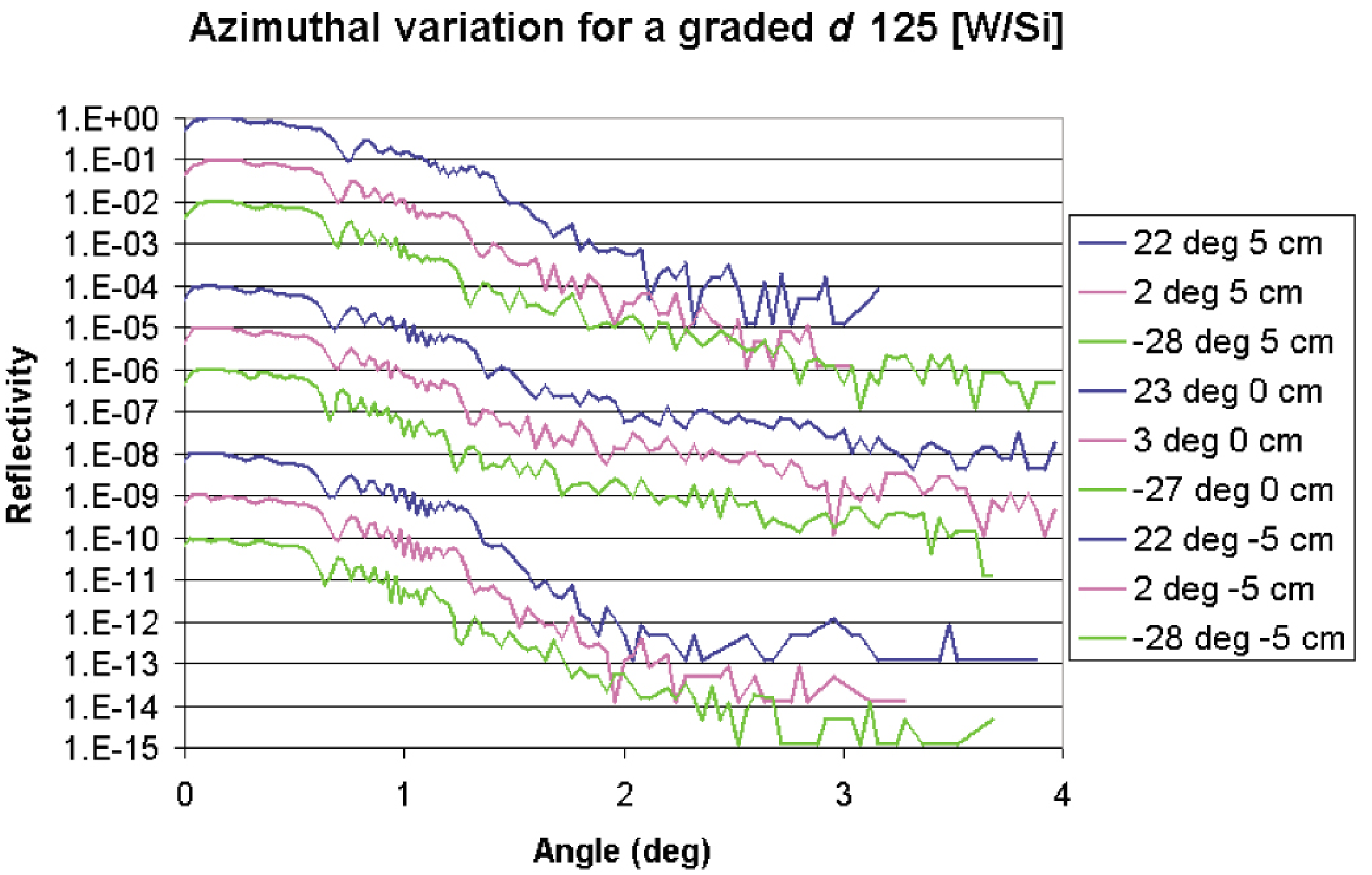
<30’’ HPD should be achievable

Depth-Graded Multilayers

Custom high-throughput chamber at DSRI can coat segments for a full mirror in 2 months (1 chamber).

Routinely produces high-reflectance multilayers in quantity

Depth-Graded Multilayers



Excellent uniformity. 4.0 Angstrom interface widths

Segmented Glass Optics

Development Plan for this year

Produce epoxy replica substrates from 20 cm long, 400μm thick glass for 3 full-shell prototype, and for coating tests. (GSFC)

Mount GSFC epoxy substrates at Colorado Precision Products (CPPI). (Columbia/LLNL)

Coat sample substrates with depth graded multilayers and evaluate for reflectance. (DSRI)

X-ray test prototype optic. Evaluate reflectance and HPD. (DSRI, Columbia, GSFC)

Segmented Glass Optics

Technical issues to be demonstrated

- Demonstrate the fabrication processes
  - Epoxy layer introduces mechanical considerations in mounting process (e.g. spacer gluing)
- Verify projected resolution
- Demonstrate that high-quality multilayers can be sputtered directly onto epoxy surface
  - Replication has been demonstrated for InFocus, and could be used

Hard X-ray Detectors

Currently no Con-X funding for this (except to support mission-specific design study)

Significant progress from balloon payload development, SR&T

Some progress/new results from last-year's Con-X effort

Some effort is planned for future FY (funding permitting)

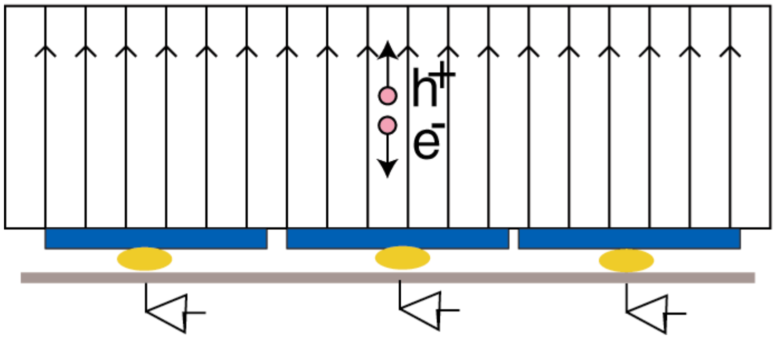
Con-X Sensor Requirements

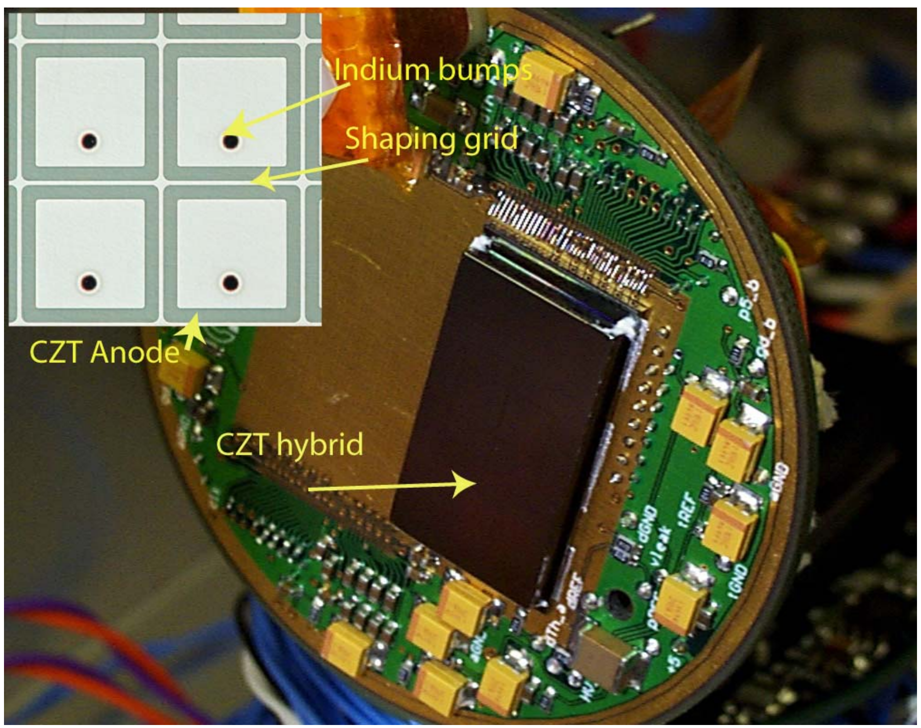
Con-X sensor parameters, performance goals

Parameter	Con-X HXT
pixel size ($1/4*\Delta\theta*f$)	<720 μm
energy band	1 - 60 keV
fwhm energy resolution	<1.2 keV (6 keV)
dimensions (FOV*f)	2.3 x 2.3 cm
quantum efficiency	>90% (6 - 60) (t_{CZT}> 0.7 mm)
trigger req'd	yes
max countrate	100 cts/s/pixel 500 ct/s/module
typ. countrate	few ct/s/module
time resolution	10 μs

- Low-electronic noise for low threshold
- Moderate-> small pixels
- moderate countrate with good time resolution
- trigger required for shield readout

CdZnTe Pixel Detectors





Selected CdZnTe for sensor

- high atomic number
- wide band gap - no cryogens

Top contact contiguous

Bottom contact (anode) segmented into pixels

Each contact is connected via Indium bump bonding to a separate readout

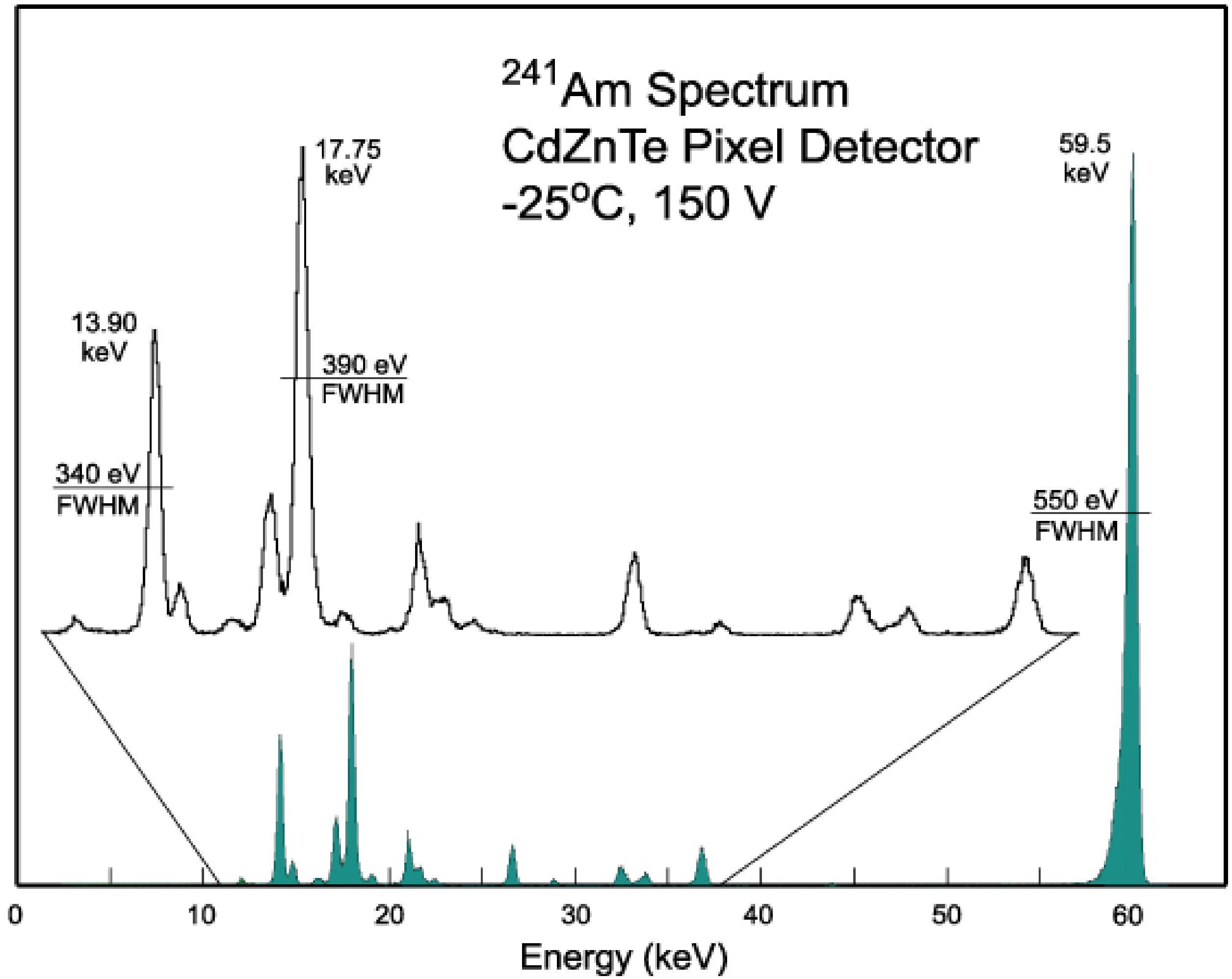
- 1-to-1 correspondence between # readout channels and # pixels

CdZnTe Development Status

Development largely leveraged from balloon experiments (HEFT, Infocus)

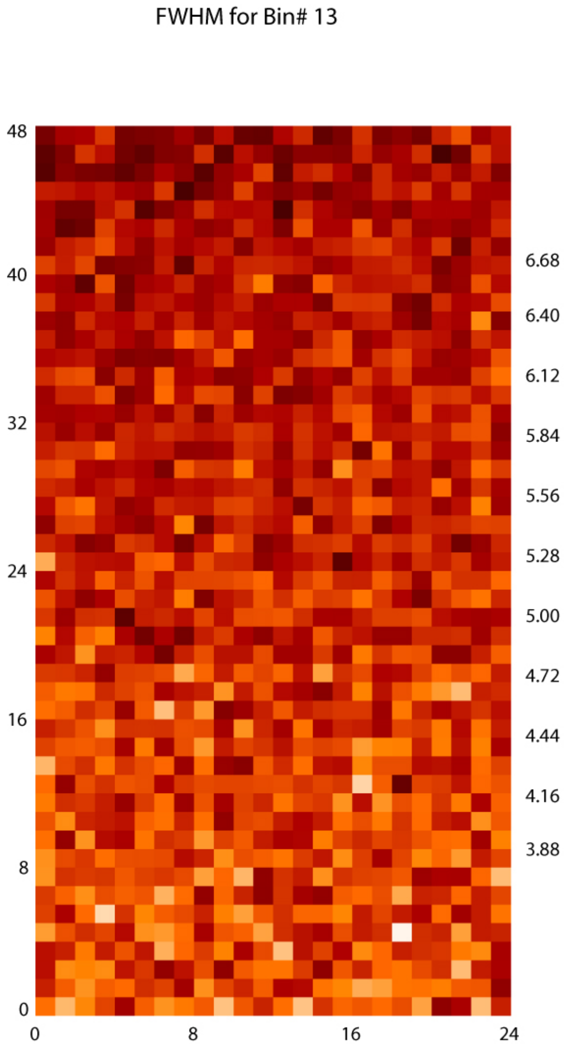
Low noise readout demonstrated

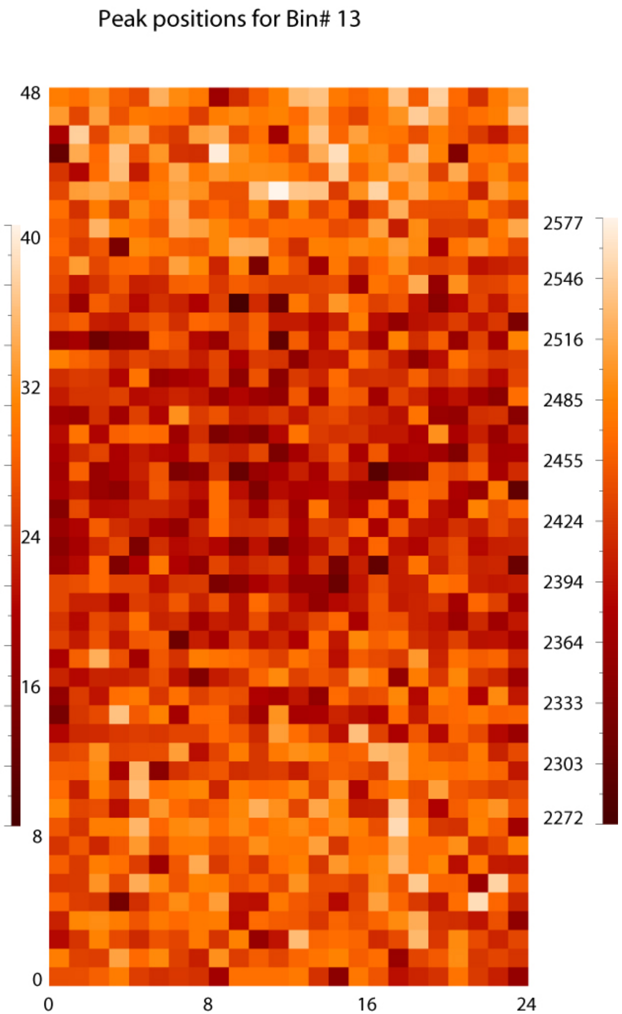
Pixel detectors fabricated and bonded to readout, demonstrating performance



500 µm CdZnTe detector/VLSI readout

CdZnTe Recent Progress





Full-size (24 x 48 pixel) low-noise ASIC demonstrated

650 eV FWHM electronic noise (10deg C)

900 eV FWHM at 60 keV

CdZnTe Recent Progress

New material from Imarad

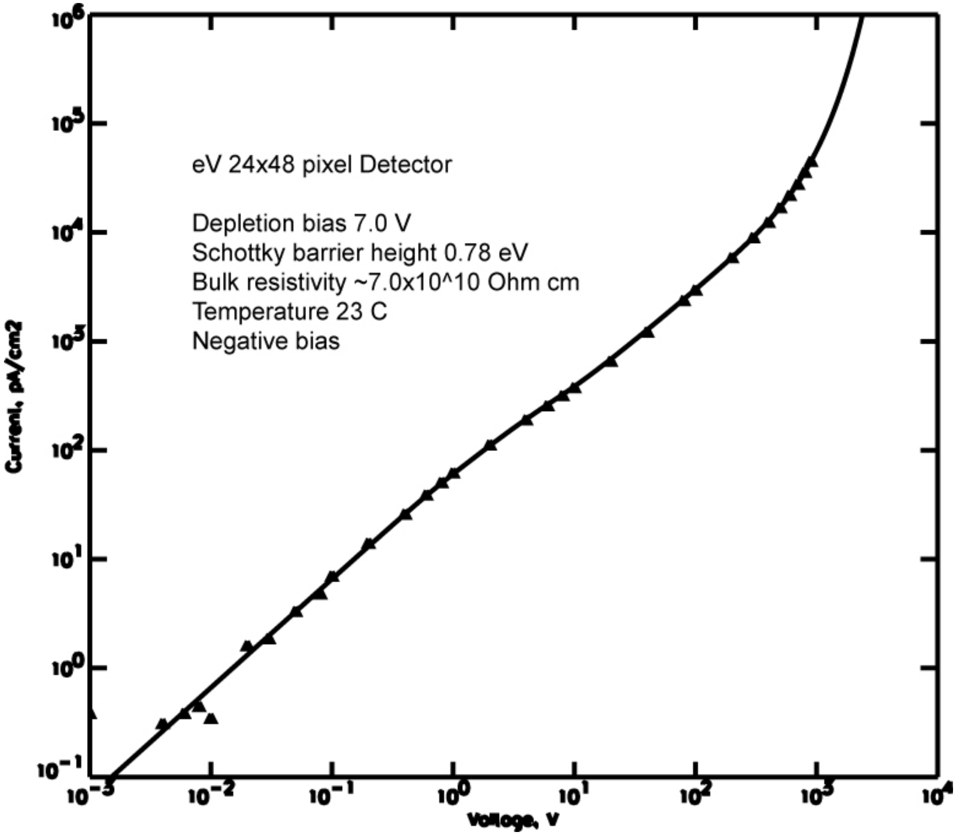
- less expensive
- potentially available in larger crystals routinely

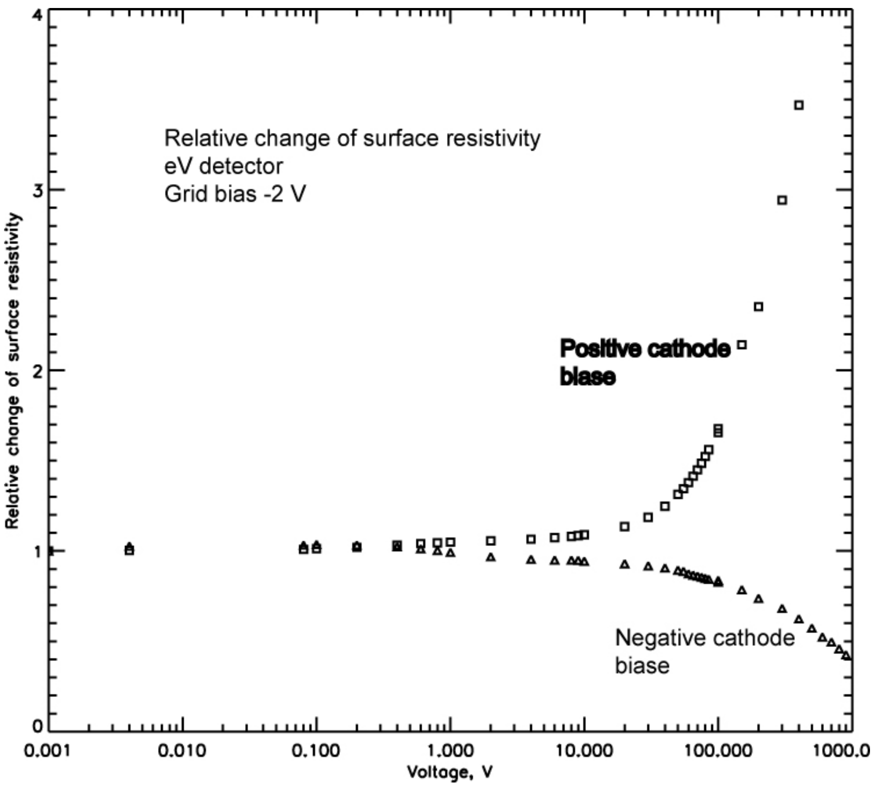
Large leakage current for standard (Au) contacts

Samples produced and Pt blocking contacts developed at GSFC (for Con-X)

Evaluated at CIT

CdZnTe Recent Progress





CdZnTe Development Requirements

Low-energy threshold and QE

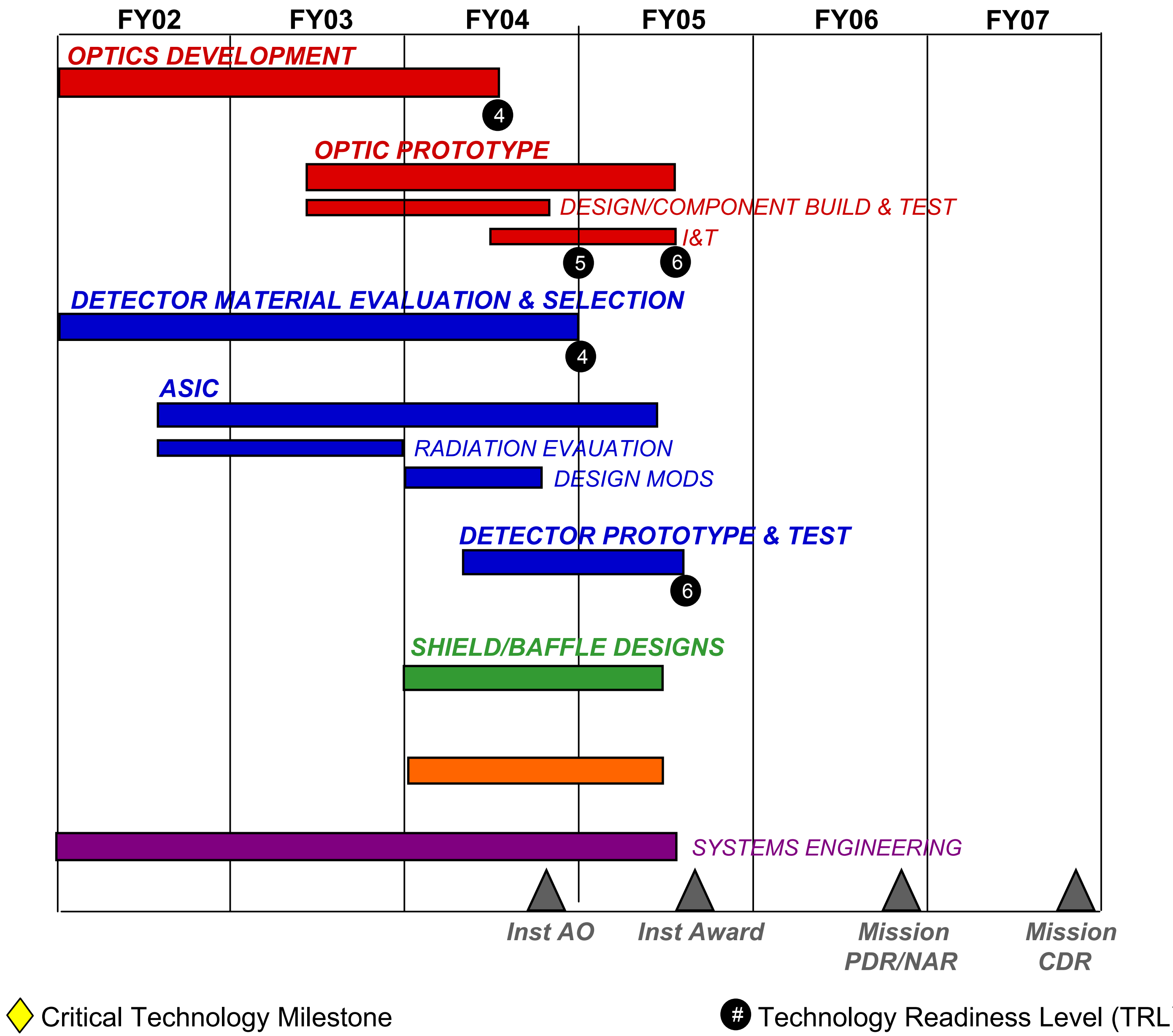
- readout threshold must be reduced from 8 keV -> 5 keV
- Efficiency of different materials must be evaluated at E < 20 keV

Sensor Packaging

- Packaging (bonding) techniques must be verified

Background and radiation damage

- Sensitive to e- trapping. Evaluate candidate materials (possible requires annealing)
- Background model must be developed
  - Shielding optimization affects instrument mass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