International X-ray Observatory (IXO)

Mirror Technology Development for IXO

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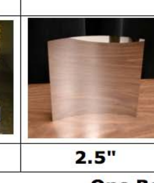
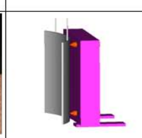
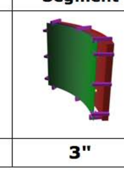
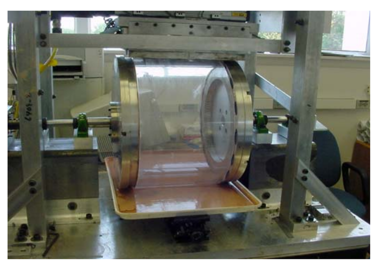
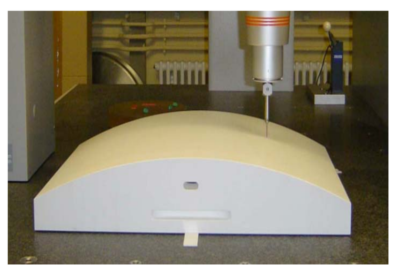
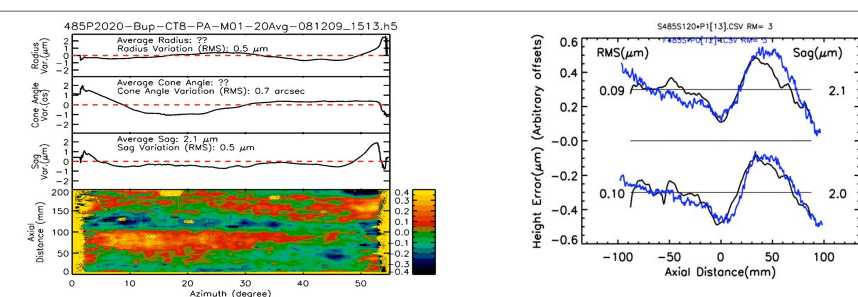
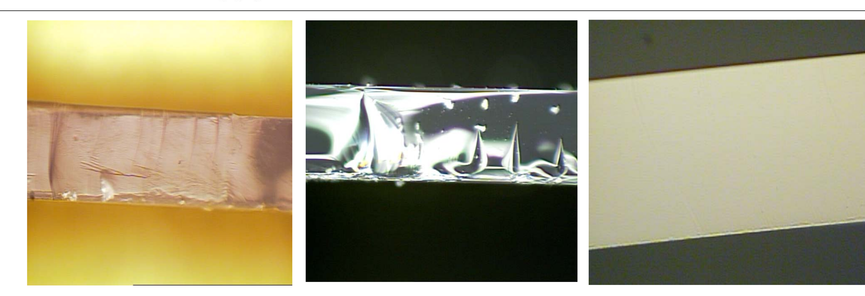
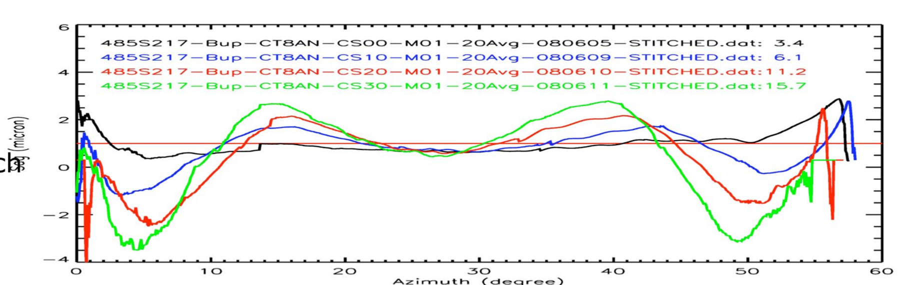
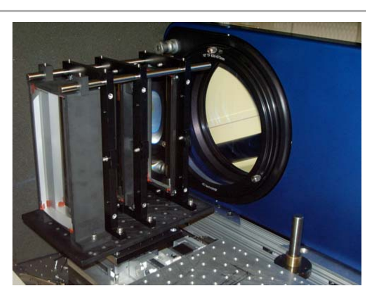
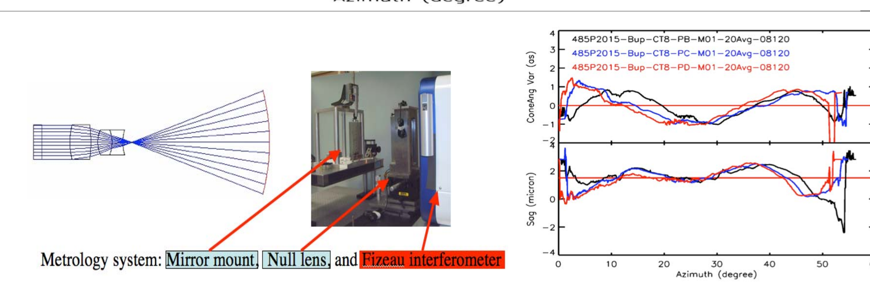
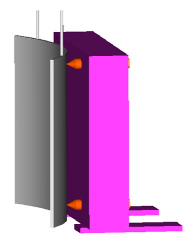
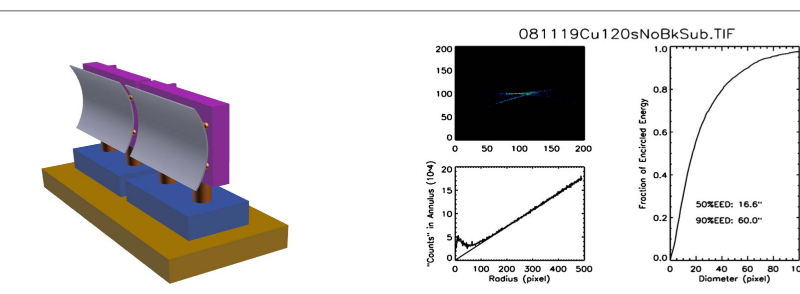
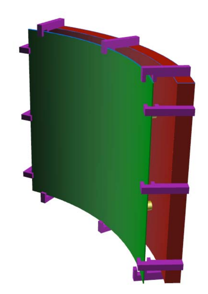
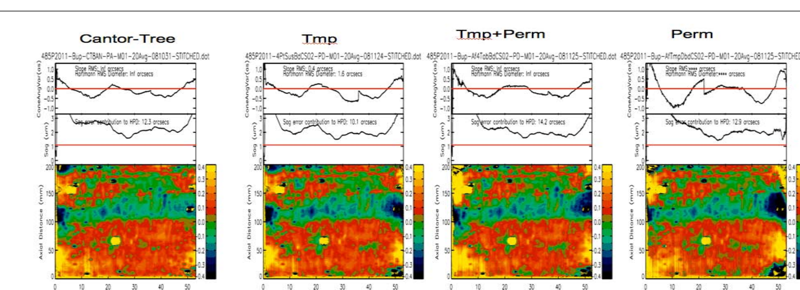
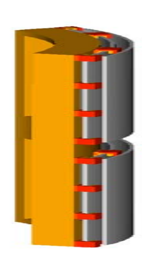
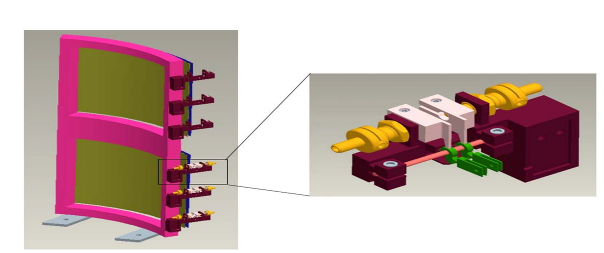
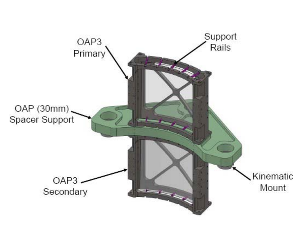
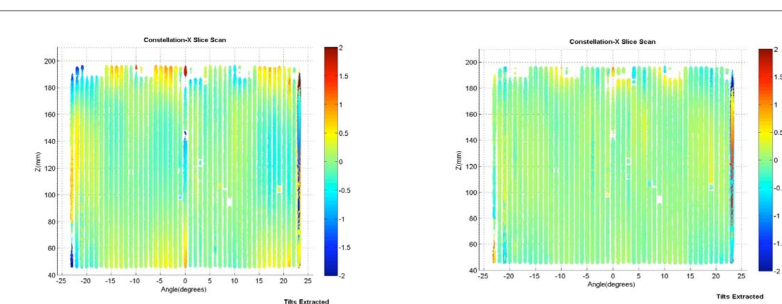
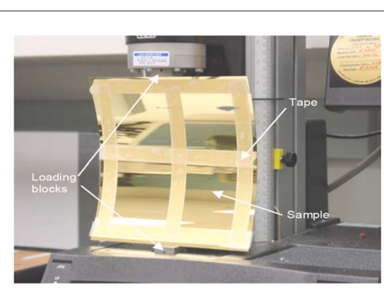
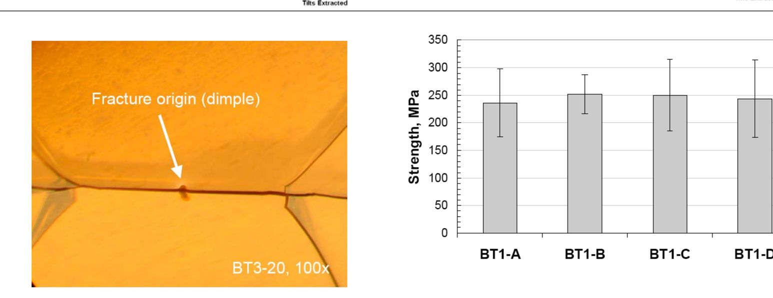
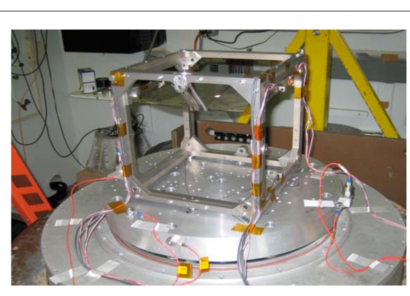
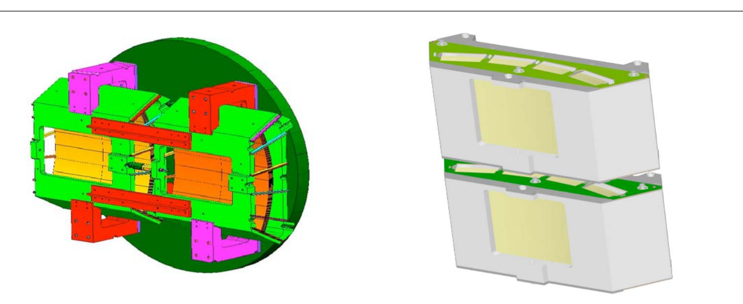
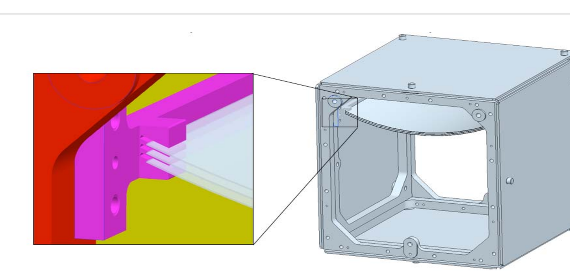
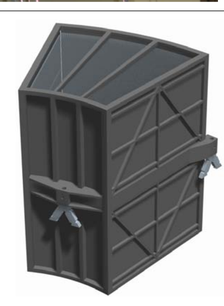
Image Error Allocation	Forming Mandrel	Mirror Segment	Mirror Segment on Transfer Mount	Permanently Bonded Mirror Segment	Permanently bonded and Aligned Mirror Pairs	Mirror Module	Flight Mirror Assembly
							
	1.5"	2.5"	2.6"	3"	4.3"	4.6"	4.9"
	One Bounce HPD				Two Bounce HPD		

Technology Component			Lead	Objectives	Status
Forming Mandrels	For Tech Development		Timo Saha	1. Fabricate mandrels that enable the development of the glass slumping process and other aspects of technology development; 2. Identify and test potential mandrel fabrication technologies that meet mandrel requirements; 3. Identify and test potential mandrel materials that meet requirements	1. Two pairs of fused quartz mandrels (485P and 485S, 494P and 494S) have been successfully fabricated; They perform at ~7 arcsecs HPD (two reflections). The dominant errors are: sag errors and low order axial figure errors; 2. A third pair (489P and 489S) is being figured and is expected to perform at ~2 arcsecs HPD (two reflections) when completed early next year; 3. A stainless steel mandrel has been precision-turned and is being polished and figured; When finished it is expected to perform at better than 10 arcsec HPD (two reflections) level and demonstrate that stainless steel is a viable mandrel material
	For Mission Implementation		Peter Blake	1. Canvass industry and the commercial market to identify and develop interested companies that have the capability of making forming mandrels; 2. Develop synergistic relationships with other space and ground-based astronomical projects to share mandrel fabrication technology development cost and expertise; 3. Develop detailed technical requirements and production plan	1. Procured 3 integral parabolic-hyperbolic mandrels from Zeiss with HPD (two reflections) at ~6 arcsec levels; 2. Issued a Request for Information to industry and received informative responses from a number of companies, including Zeiss, Tinsley, Brashear, etc., indicating that they are capable of meeting IXO technical requirements and they need additional facility buildup to meet production rate and schedule requirements; 3. Communicating with researchers at Cranfield University in the United Kingdom to investigate whether their fabrication technology for making ELT mirror segments can be used for making IXO mandrels; 4. Developing a fast and accurate metrology technique for measuring segmented mandrels
Mirror Segment Fabrication	Slumping		William Zhang	1. Develop the glass slumping process to replicate the figure of the forming mandrel to thin glass sheets as accurately as possible; 2. Preserve the natural microroughness of glass sheets; 3. Simplify the process to enable easy implementation for mass production	1. Made mirror substrates that, as far as we can measure, are identical to the mandrel in low frequency figure: 5 arcsecs HPD (two reflections); 2. These substrates preserve the good microroughness of the glass sheets: 0.5 nm RMS; 3. These substrates have mid-frequency errors resulting from 3 possible sources (a) mandrel release layer; (b) forming mandrel itself which has not been adequately measured; and (c) the glass sheets themselves 
	Cutting		James Mazzarella	1. Cut slumped (curved) glass substrates to required dimensions for alignment and integration into mirror modules; 2. Create smooth and fracture-free edges to minimize the probability of glass breakage; 3. Do so without leaving behind stress that may distort figure near the edges	1. Invented a hot-wire technique to cut curved thin glass, achieving very smooth and fracture-free edges; 2. Working on more accurate location of hot-wire tip with respect to optical axis to achieve more accurate edges; 3. Pictures on the right show a comparison of mirror edges resulting from three different cutting techniques: laser, carbide, and hot-wire 
	Coating		Lawrence Olsen	1. Sputter-coat bare glass substrates with ~15nm of Ir to maximize their X-ray reflectivity; 2. Sputter-coat ~3nm of C on top of the Ir coating if necessary; 2. Understand and minimize coating stress to preserve substrate figure; 3. Investigate possibilities of using sputter-coating to correct low-order substrate figure errors: radius, cone angle, and sag.	1. Demonstrated coating stress can significantly change the mirror sag; 2. Most of mirror sag error is caused by coating; 3. Demonstrated that a Cr-Ir bi-layer coating can result in much smaller sag error than Ir coating alone 
	Metrology		John Lehan	1. Use interferometric methods and other necessary means to definitively measure the "free-standing" figure of the mirror substrates; 2. Provide feedback to the mirror fabrication process (slumping and coating); 3. Establish the figure for down-stream steps (alignment and integration) so that they can minimize mirror distortion or improve mirror figure; 4. Enable accurate comparisons of substrate and forming mandrel figures	1. Designed, fabricated, aligned, and commissioned a 36-deg null lens; 2. Invented Cantor-tree mount for holding mirror segments; 3. Designed, fabricated, aligned, and commissioned a 60-deg null lens, making possible complete, fast, and accurate whole surface metrology of mirror segments; 4. Achieved excellent repeatability in measuring circularity, cone angle variation, and sag. 
Mirror Alignment and Integration Process Development — Optical Aspects	Transfer Mount		Kai-Wing Chan	1. Develop methods to temporarily attach a mirror segment to a holding-fixture (e.g. a strongback) with acceptable distortion; 2. Convert the flexible mirror segment into a rigid structure that can be manipulated for the purpose of alignment and integration, taking into account gravity, thermal and other considerations; 3. Develop methods to maximize the number of bonding points without introducing unacceptable figure distortion; 4. Bond and align mirror pairs for x-ray tests	1. Achieved excellent repeatability in bonding mirror segment at four points; 2. Achieved good initial results in bonding mirror segments at eight points; 3. Conducted successful X-ray tests of mirror segments, confirming performance prediction based on normal incidence metrology; 4. Working toward increasing number of bonds from 4 to 6 to 8 
	Permanent Bonding		Kai-Wing Chan	1. Develop a reliable and repeatable process to transfer a mirror segment from its transfer mount to a permanent mount with acceptable distortion; 2. Find ways to bond the mirror along its edges at as many points as possible with acceptable distortion; 3. Increase the number of boding points and the area size of each bonding point as much as possible with acceptable figure distortion	1. Successfully and repeatably transferred mirror segments from temporary mounts to permanent mounts with four permanent bonding points; 2. Completed each transfer process in less than two hours; 3. Investigated many different bonding geometries both experimentally and using finite element analysis tools 
	Housing Simulator		Kai-Wing Chan	1. Combine knowledge accumulated from "Transfer mount" and "Permanent Bonding" to align and bond at least two pairs of mirror segments onto a rigid structure that simulates a module housing; 2. Preserve alignment in the process; 3. Enable X-ray tests of truly permanently bonded mirrors segments with no further adjustment	1. Designed and built a vertical optical beam facility to perform mirror pair alignment; 2. Completed preliminary design of a housing simulator structure with changeable bonding tabs; 3. First version being fabricated and expected for delivery by the end of January 2009 
	Optical Alignment Pathfinder		Paul Reid	1. Demonstrate an adjustable mounting and alignment of mirror segments without distorting axial figure using a flight-like mount; 2. Provide capability to adjust segment pair focal length thru a broad range by changing segment cone angle to account for manufacturing tolerances of segments and mandrels; 3. Provide low stress mirror support under vibro-acoustic launch loads	1. Changed mirror pair focal length error of ~ 112 mm out of 8400 mm nominal focal length; 2. Measured figur before and after bonding and showed no change down to level of metrology repeatability (~ +/- 2 arc_sec HPD equiv.); 3. Aligned mirror segment pair to approx. factor of 2 of error budget allocation; 4. Structural analyses of mount showed to be consistent with minimal launch stresses 
Mirror Alignment and Integration Process Development — Mechanical Aspects	Glass Strength Test		Charles C. He	1. Determine statistically the break strength of glass sheets as received, after slumping, after coating etc.; 2. Identify mechanisms of failure; 3. Develop glass screening techniques that can identify weak or weakened mirror segments so that they will not be part of the final mirror assembly	1. Performed bi-axial strength tests of flat glass; 2. Completed folding tests of curved/slumped glass mirrors; 3. Performed strength tests using bondings that are substantially similar to eventual flight bondings (MASO) 
	Vibration Test		Ryan S. McClelland	1. Vibrationally test single and multiple mirror segments mounted in different housings and in different configurations to characterize system response and mirror survability; 2. Develop computer models that adequately explain test results; 3. Devise input to module design to eliminate mirror segment breakage	1. Vibrated multiple mirror segments mounted in aluminum housings, mirror segments survived beyond the most severe vibrational environment expected during launch; 2. Performed preliminary analysis indicating that mirror segments can survive launch environment when properly bonded at sufficient number of points. 3. Demonstrated ability to accurately predict mirror response to random vibration environment. 
	Acoustic Test		Ryan S. McClelland	1. Acoustically test single and multiple mirror segments mounted in different housings and in different configurations to characterize system response and mirror survability; 2. Develop computer models that adequately explain test results; 3. Devise input to module design to eliminate mirror segment breakage	1. Successfully acoustically tested a mirror segment in a rigid housing simulator at the expected launch vehicle acoustic levels; 2. Conducting a similar test using three mirror segments in a more flight-like housing simulator. 
Mirror Module Design and Buildup			Ryan S. McClelland	1. Synthesize all knowledge accumulated directly and indirectly into a module design that will meet all requirements: angular resolution, effective area, mass, vibro-acoustic environment, etc.; 2. Build a module that will contain as many pairs of mirrors as there are forming mandrels; 3. X-ray test and vibro-acoustically test this module to demonstrate that the mirror technology has reached TRL-6	1. Worked out alignment and integration process conceptually; 2. Arrived at a preliminary design of Module that meets both mass and effective area requirements; 3. Simulated performance of preliminary Module design using integrated optomechanical analysis. 4. Working on thermal design and analysis; 5. Working on acoustic and vibration analyses and tests