Auxiliary Optical Systems - AOS

Stray Light Control and Viewports – SLC

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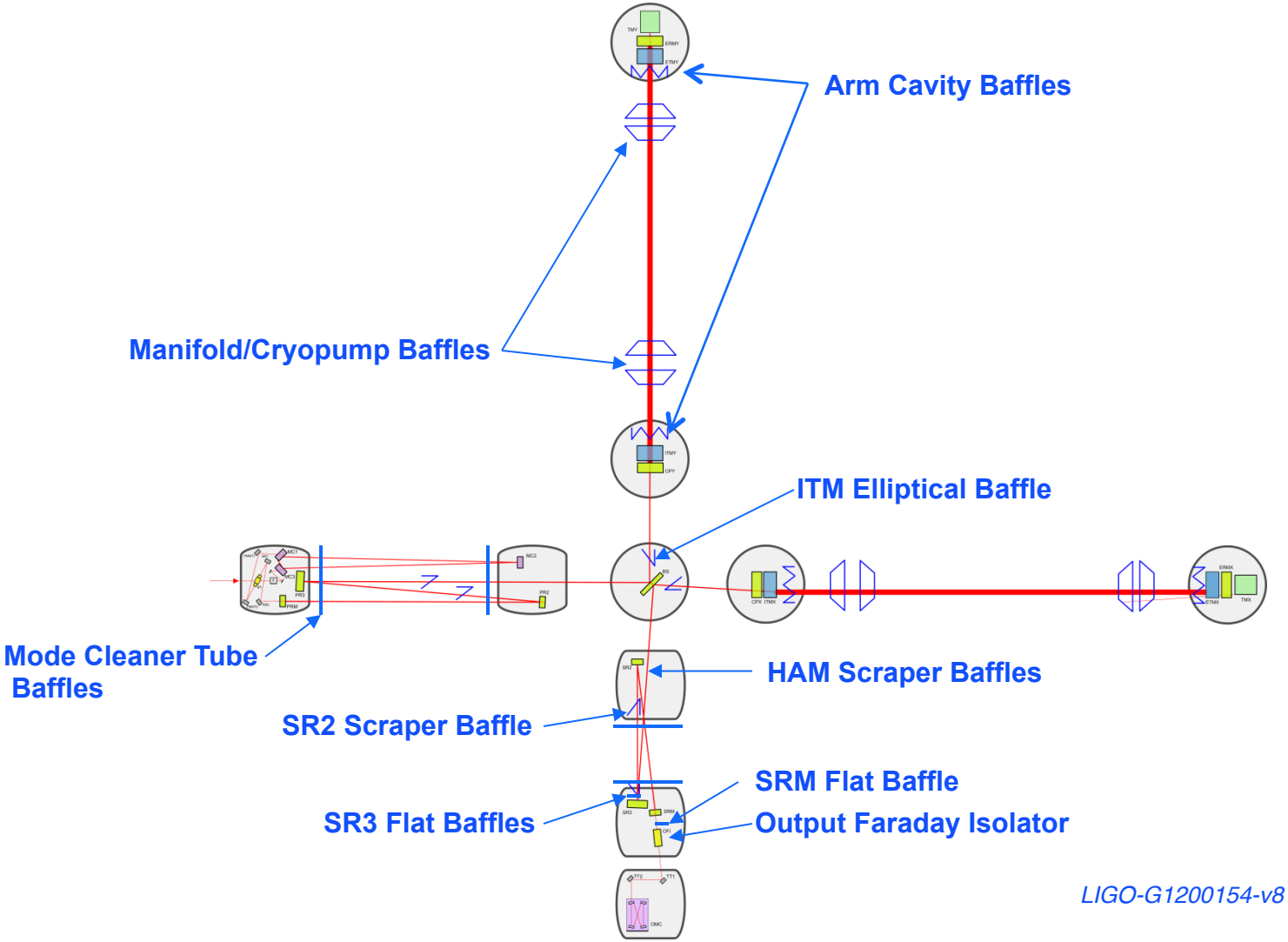
(Cognizant Optical Engineer)

aLIGO NSF Review
LIGO Hanford Observatory

April 11-13, 2012

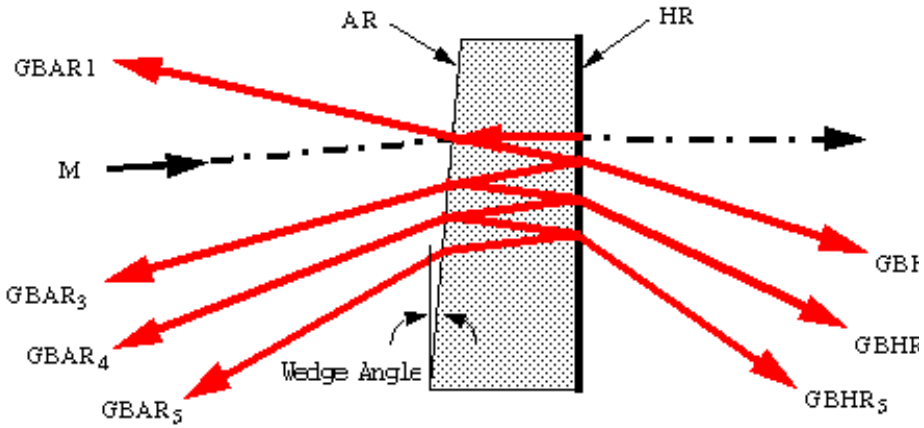
LIGO-G1200154-v8

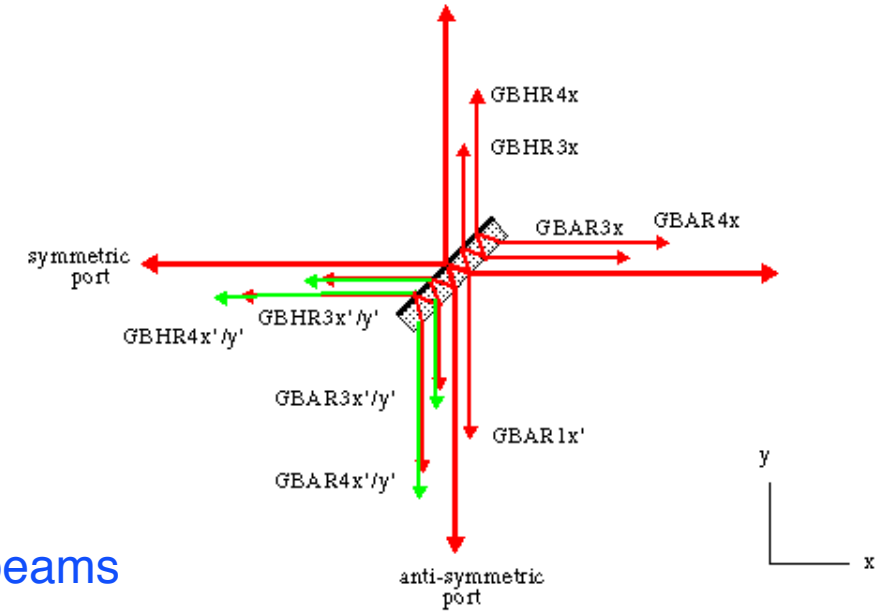
Stray Light Control - SLC



Stray Light Control Functions

- Control stray light scatter in the interferometer using baffles, beam dumps, and attenuators
- Reduce scattered light displacement noise

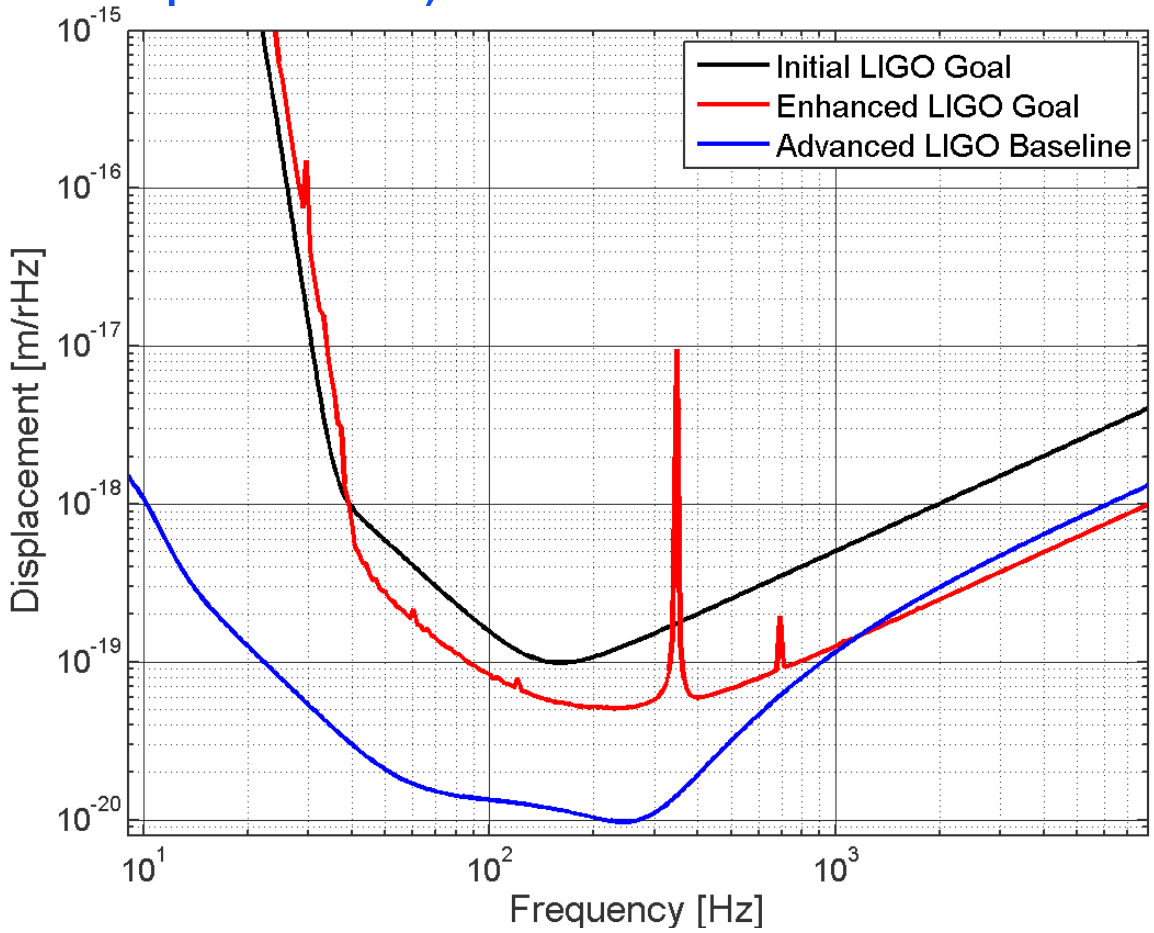




Ghost beams

LIGO Stray Light Control Requirements

- Total stray light displacement noise <1/10 Thermal noise (Coatings and suspensions)



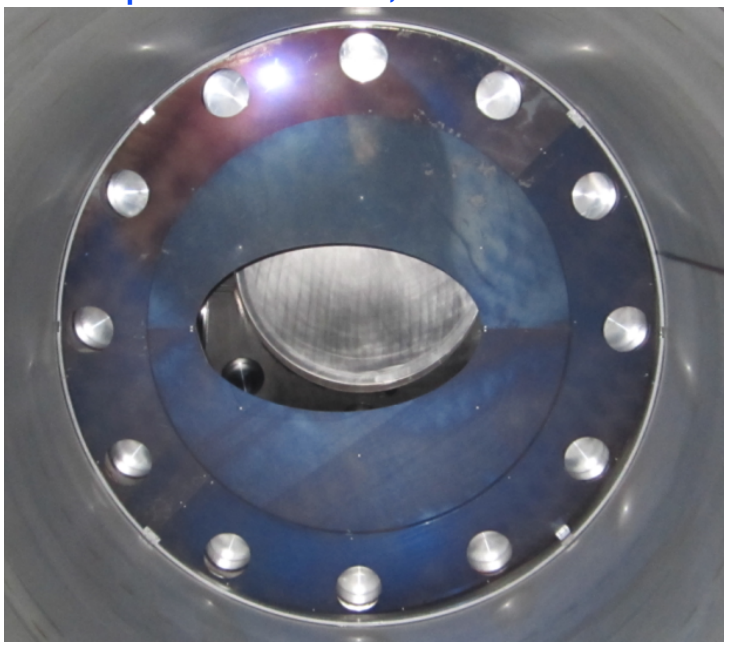
Stray Light Control Design Concept

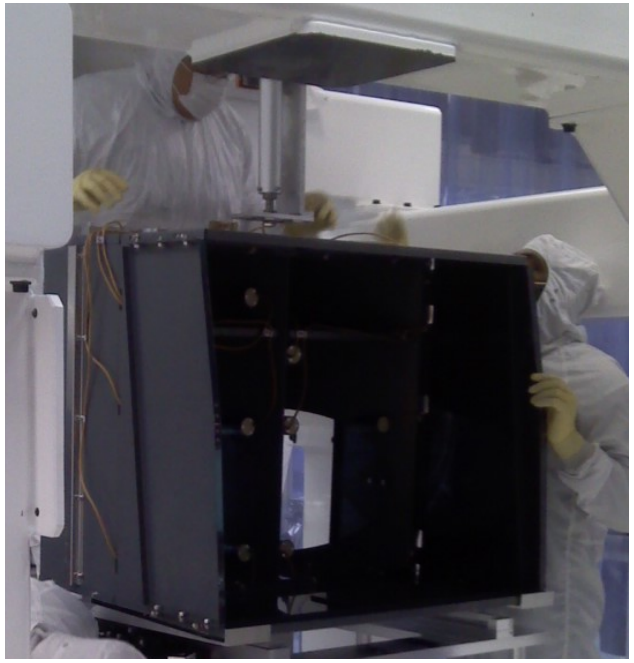
- Oxidized, polished SS, low BRDF stable surface baffles
- Small, Core Optic wedge angles simplify/consolidate many baffles and beam dumps in the recycling cavities
  - » Cavity Mirror Wedge angles
    - – ITM, 0.076 deg vertical wedge angle causes ghost beams to separate from the main beam in the vicinity of PR2 and SR2 for interception with beam dumps
    - – BS, 0.074 deg horizontal wedge angle provides the ITMX Hartmann beam in vicinity of SR2
- Suspended baffles reduce scattered light displacement noise for critical scattering paths
  - » Arm Cavity Baffle (ACB), ITM Elliptical Baffle, Manifold/Cryopump Baffle
  - » Output Faraday Isolator
- ACB catches narrow and wide-angle scatter from ITM and ETM
- ACB photodetectors aid initial alignment and measure scattered light from TM
- Mode Cleaner Tube Baffle mitigates recycling cavity scatter and errant beams

Scattered Light Control Development Accomplishments - I

- Measured vibration of suspended Output Faraday Isolator (OFI) and Arm Cavity Baffle (ACB) with eddy current-damping at Caltech and LASTI - meet SLC displacement noise requirement
- Measured the BRDF of oxidized, polished stainless steel baffles and beam dumps for stable, low BRDF surfaces

Mode Cleaner Tube baffles for recycling cavities



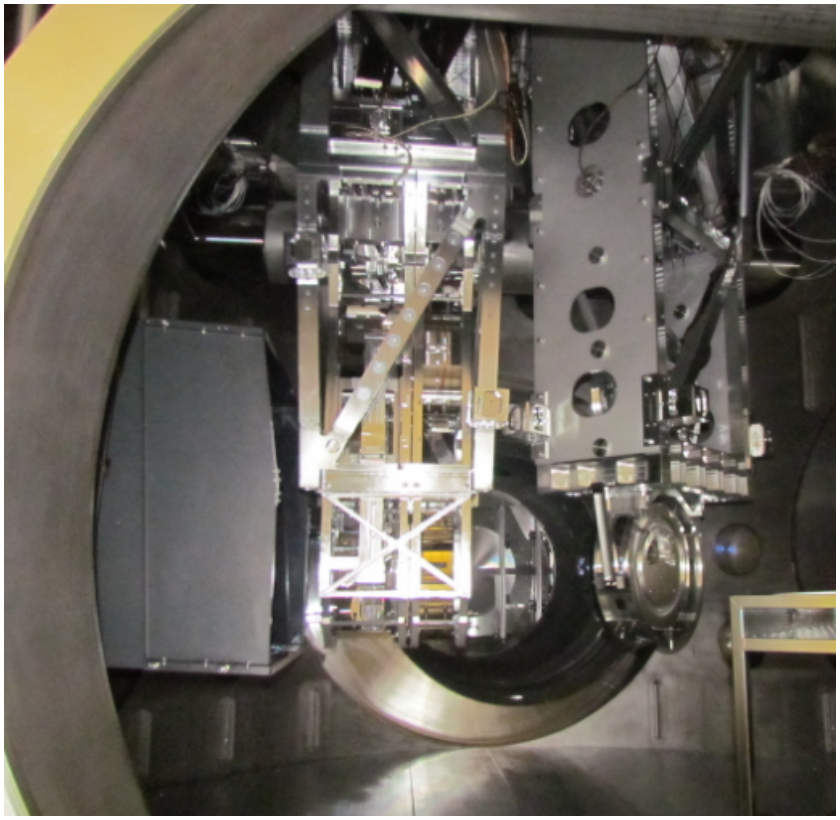


Arm cavity baffle design mitigates wide-angle scatter from Test Mass

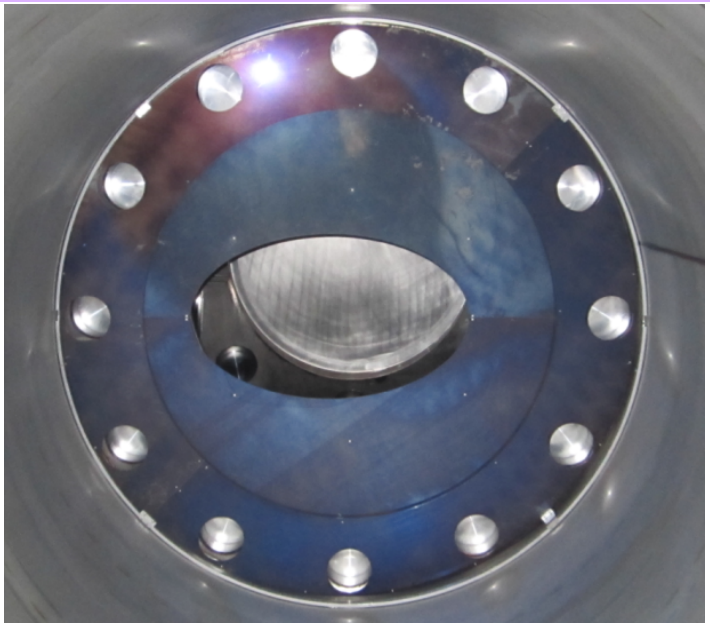
Scattered Light Control Development Accomplishments – II

- Completed Installations:

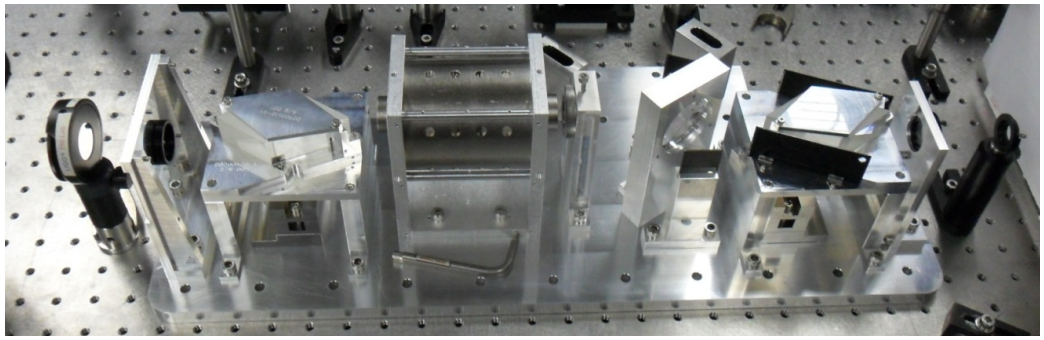
Fold Mirror Elliptical Test Plate – BSC8, LHO



Arm Cavity Baffle – BSC8, LHO



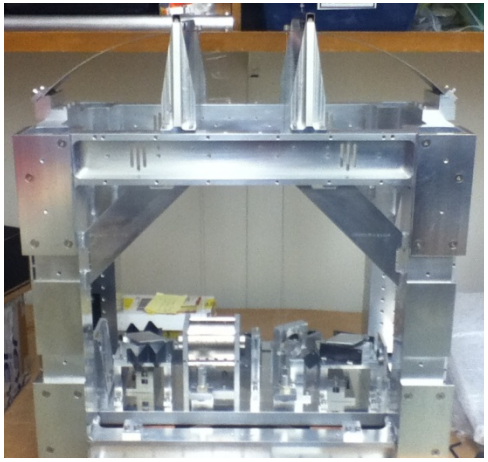
Mode Cleaner Tube Baffles, LLO



OFI in Squeezer test at LHO

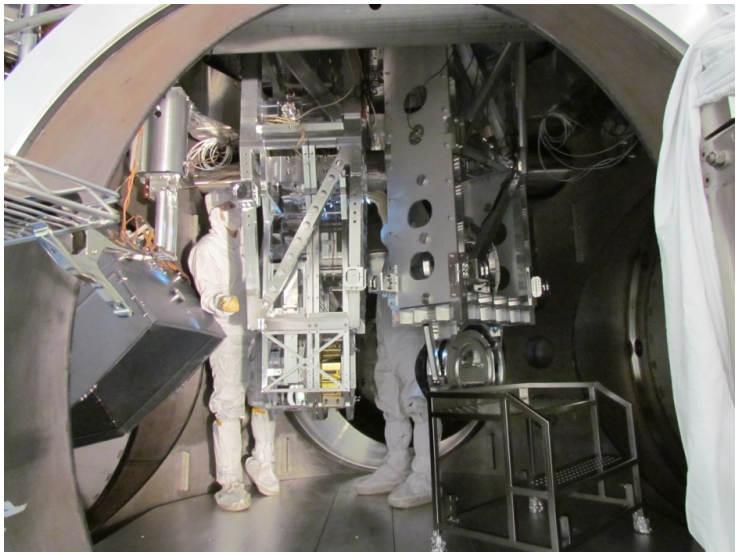
Scattered Light Control Development Accomplishments – II

Oxidized stainless steel processing

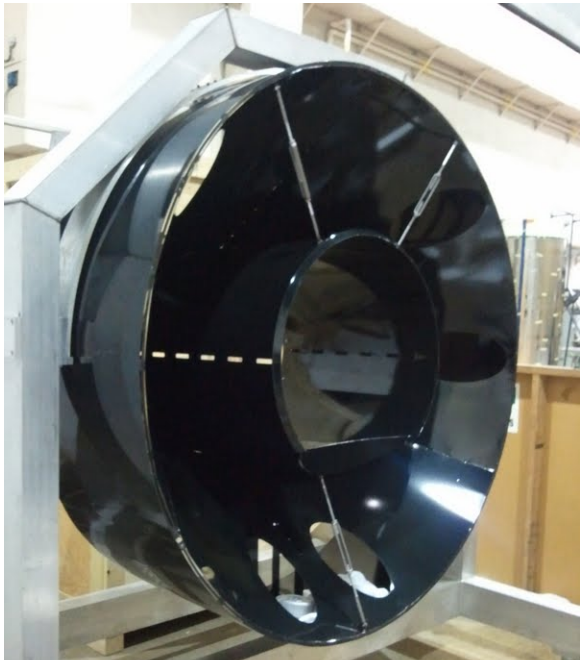


OFI
1st article
assembly

Air Cavity Baffle in swing back position

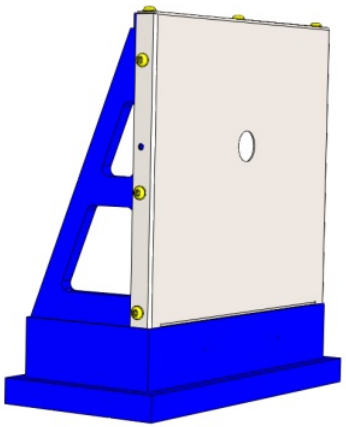


Assembly and vibration testing of prototype, suspended Manifold/ Cryopump Baffle at Caltech

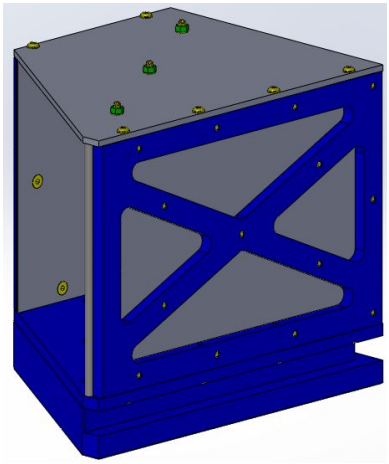


Stray Light Control Development Status

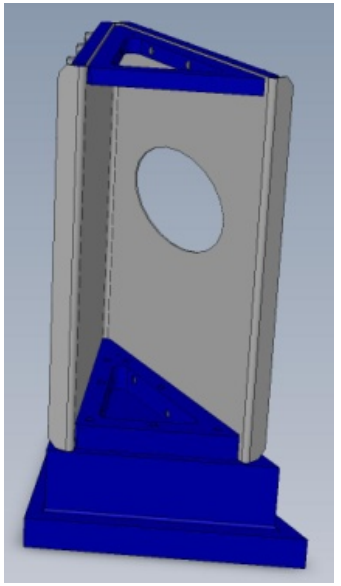
- All designs and drawings are complete
- Completed Final Design Reviews
  - » Arm Cavity Baffle
  - » Mode Cleaner Tube Baffle
  - » Manifold Cryopump Baffle
  - » Signal Recycling Cavity Baffles and Beam Dumps
  - » ITM Elliptical Baffle



SRC - SRM HR Baffle



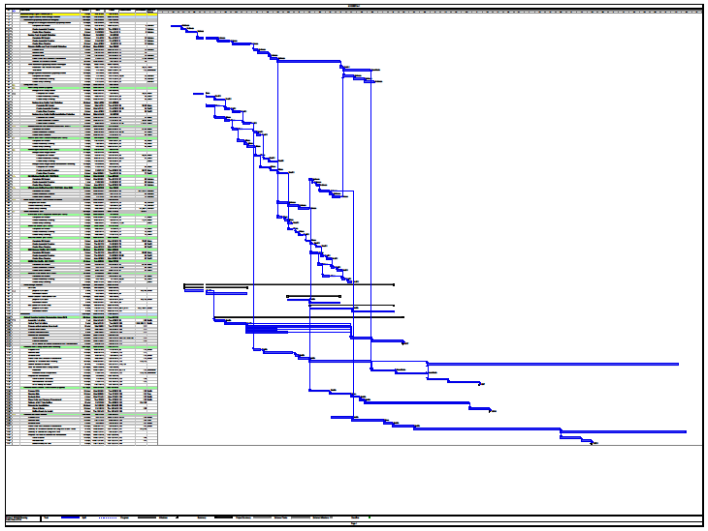
SRC - SR2 Scraper Baffle



SRC - HAM Scraper Baffle

Stray Light Control
Project Plans and Organization

- Project Plans
  - » Baffles and Beam Dumps for Michelson Integration ready – April 2012
  - » All Baffles and Beam Dumps for aLIGO Installation – complete by November 2012
- Project Organization - Caltech
  - » Team Leader – Lisa Austin
  - » Cognizant Engineer – Michael Smith
  - » Coordinator – Nichole Washington
  - » Suspensions Testing - Virginio Sannibale
  - » Mechanical Designer - Heidy Kelman
  - » Mechanical Designer – Manuel Ruiz
  - » Mechanical Designer – Tim Nguyen



Scattered Light Control LIGO-India Impact

- Arm Cavity Baffle
  - » Two hole baffle option no longer required
  - » Re-evaluation of baffle weight for spring blades
  - » Re-configure ACB in H2-BSC8 for move to H1-BSC1
- Reduced scope
  - » H2 Baffles no longer required – Manifold Flat, Fold Mirror Beam Dumps and Fold Mirror Elliptical
- Manifold Cryopump Baffles will not be provided.

Scattered Light Control Challenges, Risks, and Mitigations

- Delivering SLC in time for the Michelson Integration
  - » On critical path to meet Installation Schedule
- On-time delivery of procurements
  - » Continuous monitoring of manufacturing progress
- No remaining known risks

Stray Light Control
Near Term Activities

- Procurements – April 2012
  - » Signal Recycling Cavity Baffles
  - » Manifold Cryopump Baffles
  - » Remaining Arm Cavity Baffles
- Completed Final Design Review – April 2012
  - » Remaining SLC baffles and beam dumps
- Installation Underway
  - » Signal Recycling Cavity Baffles – LLO
  - » Output Faraday Isolator - LLO
  - » Mode Cleaner Tube Baffles - LHO
- Developing installation procedures
- Modifying tooling for installation variations between sites - Done

Viewport Functions

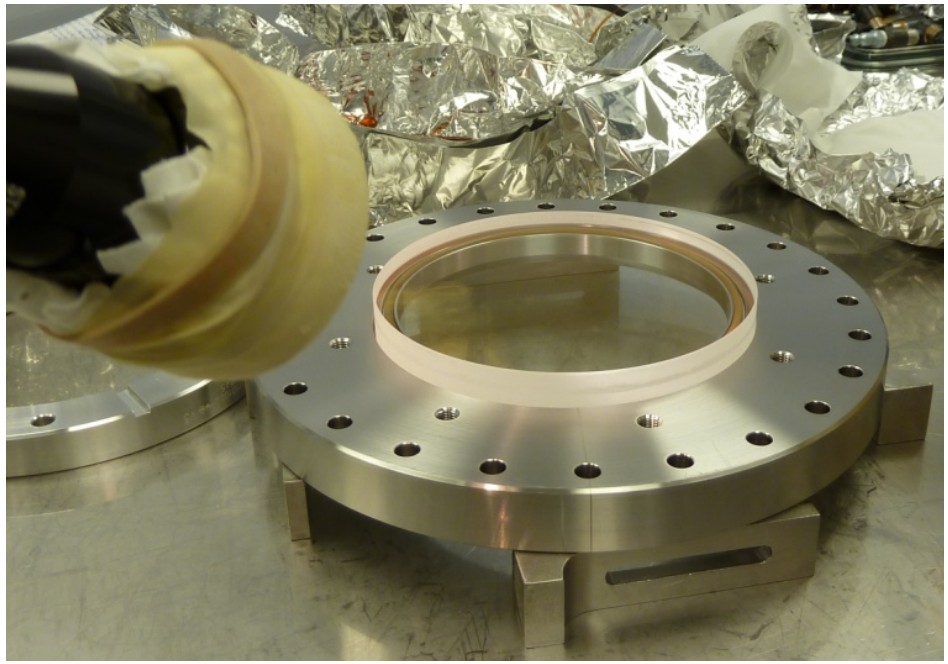
- Provide optical viewports for the passage of optical beams in and out of the vacuum region(s) of the Interferometer.
  - » Optical lever beams
  - » Chamber illumination beams
  - » Video camera beams
  - » Optical beams for interferometer sensing and control
  - » Hartmann Sensor beams
  - » Photon Calibrator beams
  - » Septum Viewports
- Double glass safety viewports for high power beams
- Provide safety covers for all installed viewports

Viewport (VP) Requirements

- Video camera VP—transmit visible light spectrum
- Chamber illumination VP—uncoated viewports
- OpLev VP—635 nm, similar to iLIGO
- Septum Plate (to isolate input and output HAM chambers) VP— similar to eLIGO
- ISC and Hartmann VP—super-polished, low scattering, < 1/10 wave , special AR coatings
  - » Hartmann AR coating: 800nm – 1080nm
  - » ISC AR coating: 532nm and 1064nm
- Safety covers to protect viewports during installation and commissioning
- High Power double glass design; High Power, Reducer & Septum Safety covers

Viewport Design Concept

- Reuse iLIGO VP wherever possible
- New O-ring-sealed 6.0 inch VP for Interferometer Sensing and Control, and Hartmann beams
- Wedged Septum VP similar to eLIGO design
- Additional standard catalog VPs needed for new Mode Cleaner Tube VPs
- Double glass for high power VP
- Special AR coatings for Video, ISC, and Hartmann beams

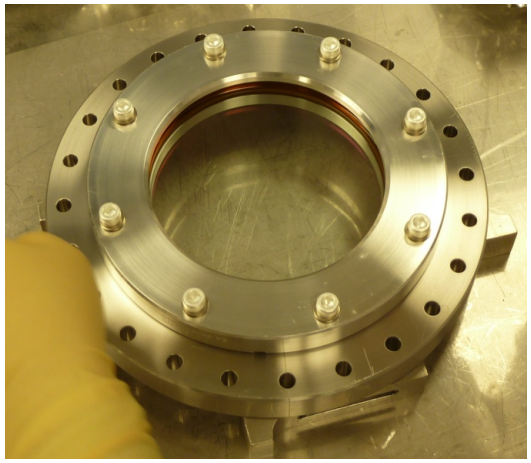


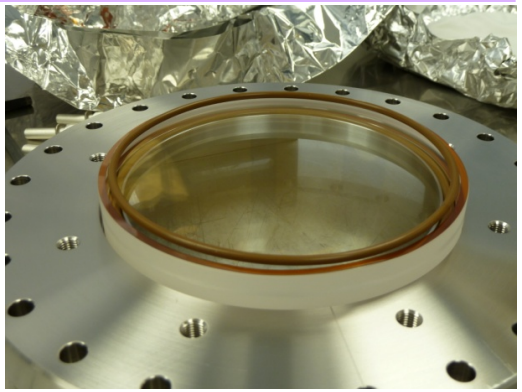
Viewport Development Accomplishments

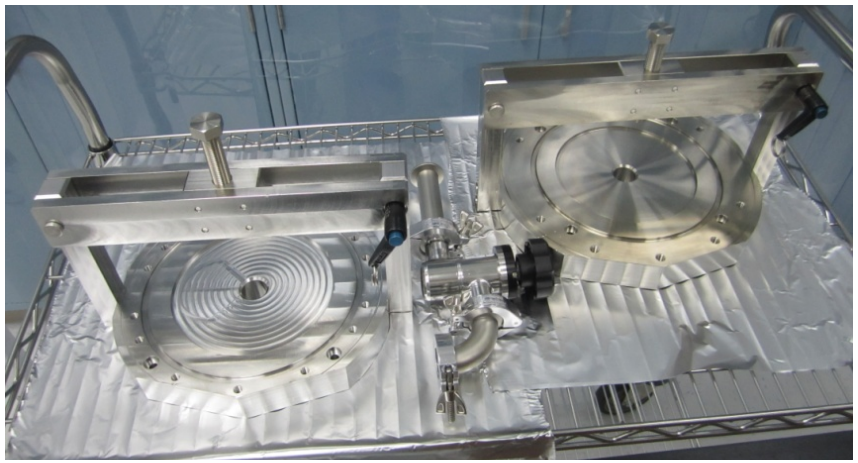
- Analyzed VP scattered light for Hartmann beams
- Determined new viewport locations in mode cleaner tubes using ZEMAX beam layout
- Established proper names for all viewports according to LIGO naming convention & created a catalog of VP requirements and part numbers for all subsystems
- Developed specification for 6.0 inch ISC/Hartmann VP
- New – Develop/modify Safety Covers for High Power VPs, Septum VPs, and VPs with flange reducers
- Completed VP Final Design Review
- Implemented over-pressure and leak testing of VPs at LLO & LHO
- Set up testing facility at Caltech for measuring VP coatings

Viewport Development Status

- Drawings and assemblies for custom 6.0 inch VP and Septum VPs - complete
- Final Design Review - complete
- VP Procurements on schedule for installation– complete
- Assembly and Test of LHO custom VP for one arm test – complete
- Assembly of LLO custom VP for SMI – complete
- Over-pressure and leak testing facility at LLO & LHO - complete
- Testing facility at Caltech for measuring VP coatings – complete



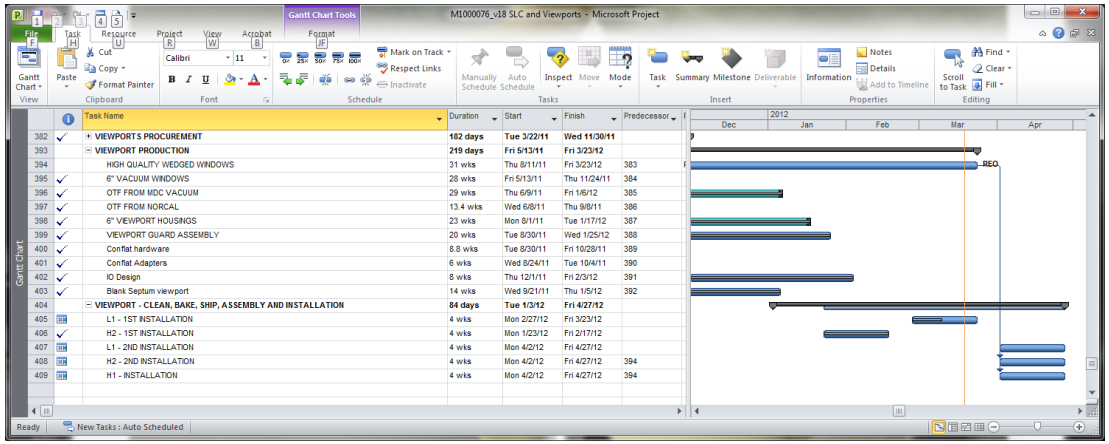




Testing fixtures

Viewport Project Plans and Organization

- Project Plans
  - » On schedule for deployment of three aLIGO IFOs
- Project Organization
  - » Leader – Lisa Austin
  - » Cognizant Optical Engineer – Michael Smith
  - » Coordinator – Nichole Washington – Caltech
  - » Assembly – Daphen Pino - Caltech
  - » Installation Leads –
    - Thomas Vo – Hanford
    - Chris Guido– Livingston



Viewport Challenges, Risks, and Mitigations

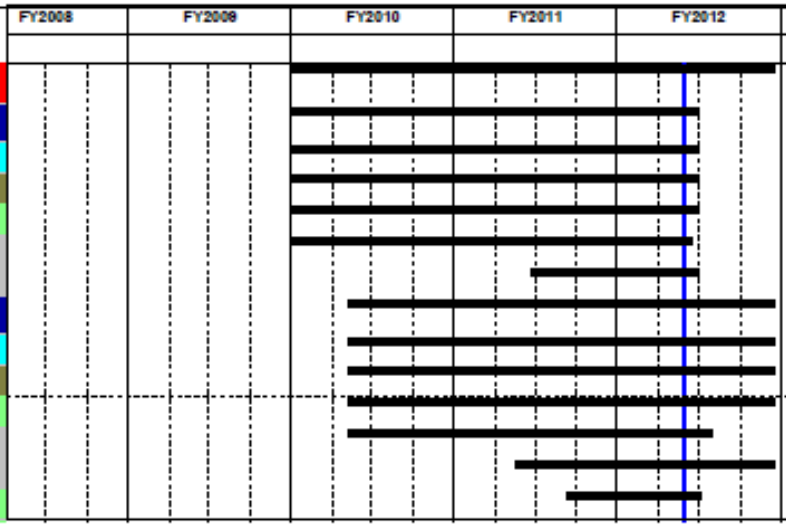
- Viewport damage during over pressure testing
  - » Fixture redesigned to eliminate stress to support ring.
- Other VPs mostly catalog items
  - » No known technical or schedule risks

Viewport
LIGO-India Impact

- No impact on design, cost or schedule.

AOS SLC Schedule Highlights

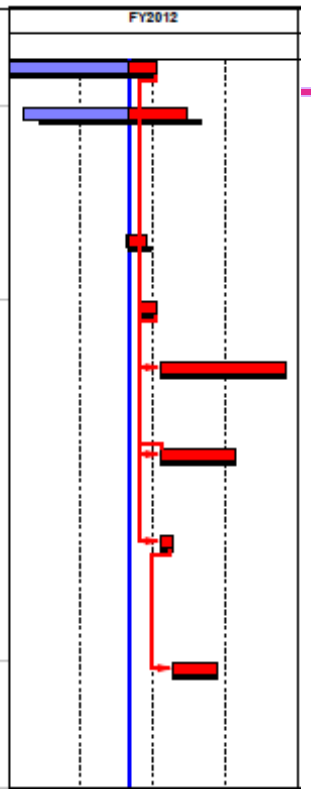
Activity ID	Activity Name	Start	Finish
LIGO	LIGO Lab Program - AdvL Current	01-Oct-09 A	17-Sep-12
LIGO.3	Advanced LIGO Development	01-Oct-09 A	30-Mar-12
LIGO.3.07	Auxiliary Optics (AOS)	01-Oct-09 A	30-Mar-12
LIGO.3.07.3	AOS Design	01-Oct-09 A	30-Mar-12
LIGO.3.07.3.3	AOS Final Design	01-Oct-09 A	30-Mar-12
LIGO.3.07.3.3.1	AOS Stray Light Control (SLC)	01-Oct-09 A	15-Mar-12
LIGO.3.07.3.3.9	AOS Viewports	22-Mar-11 A	30-Mar-12
LIGO.4	Advanced LIGO Project	10-Feb-10 A	17-Sep-12
LIGO.4.07	Auxiliary Optics Systems (AOS)	10-Feb-10 A	17-Sep-12
LIGO.4.07.4	AOS Fabrication	10-Feb-10 A	17-Sep-12
LIGO.4.07.4.1	AOS Stray Light Control Fabrication	10-Feb-10 A	17-Sep-12
LIGO.4.07.4.1.1	AOS Output Faraday Isolator (OFI) Suspension Assembly	10-Feb-10 A	27-Apr-12
LIGO.4.07.4.1.2	AOS Baffles & Beam Dumps	14-Feb-11 A	17-Sep-12
LIGO.4.07.4.A	AOS Viewports	10-Jun-11 A	04-Apr-12



- SLC Scope of Work – Includes the Output Faraday Isolator, Baffles and Beam Dumps, and Viewports.
- Schedule Highlights: All Final Designs were completed as of March 2012. All procurement and assembly are anticipated to be complete in September 2012.

AOS SLC Critical Path

Activity ID	Activity Name	Predecessors	Successors	Start	Finish	Total Float	Free Float
AO-P52010	AOS FAB SLC: RFQ thru Award Manifold/Cryo Baffles/Dumps		AO-A53640	18-Feb-11 A	06-Apr-12	-46	0
AO-A53620	AOS FAB SLC: L1 Fab/Receive/Deliver AC Baffles & BDs (BSC1,3,4,5)	AO-A52010	AO-A53630, AO-M59790, AO-A53610, AO-P51910, IN-L1-P3545, IN-L1-P3645,	21-Oct-11 A	15-May-12	-33	34
AO-F40750D	AOS FAB VP: L1 Ship, C&B, Assemble Viewports SMI Lot 1	AO-F40750B	AO-M59970, IN-L1-P2105, IN-L1-P3930	27-Feb-12 A	23-Mar-12	-58	14
AO-P52050	AOS FAB SLC: RFQ thru Award Balance of Baffles/Dumps (BDs)	AO-D51540, AO-M40733E	AO-P52060, AO-A53670	16-Mar-12	06-Apr-12	-36	0
AO-A53650	AOS FAB SLC: H2 Fab/Receive/Deliver Remaining Manifold/Cryo BDs	AO-A52030, AO-A53640	AO-A53660, IN-H2-FI2260, AO-M59810, IN-H2-FI2590	09-Apr-12	14-Sep-12	-24	0
AO-A53640	AOS FAB SLC: L1 Fab/Receive/Deliver Manifold/Cryo BDs	AO-A52030, AO-P52010	AO-A53660, AO-A53650, AO-M59790, IN-L1-P3800	09-Apr-12	13-Jul-12	-46	0
AO-A53670	AOS FAB SLC: L1 Fab/Receive/Deliver Balance of BDs	AO-P52050	AO-A53690, AO-A53680, AO-P52070, IN-L1-P3105, IN-L1-P3205, IN-L1-P3444,	09-Apr-12	24-Apr-12	-36	0
AO-A53680	AOS FAB SLC: H2 Fab/Receive/Deliver Remaining Balance of BDs	AO-A53670, AO-P52060	AO-A53690, IN-H2-FI2260, IN-H2-FI1175, IN-H2-IF2445, IN-H2-FI2030, IN-H2-FI1105,	25-Apr-12	20-Jun-12	-25	0



- Manifold Cryopump Baffles were impacted by introduction of Oxidation Process and other design changes.
- Arm Cavity Baffle - L1 lessons learned from BSC 8.
- Viewports - L1 SMI assembly is in process.
- Balance of Beam Dumps Final Design was recently completed.

AOS SLC Tracking Milestones

Activity ID	Activity Name	Baseline Target Dates	Current Dates (Feb-12)	Schedule Change (Days)	NSF Reporting Dates
AO-M59750	AOS FAB: AOS Production Begins	23-Sep-10	27-Sep-10 A	-4	N/A
AO-M47100	AOS FAB SLC: Stray Light Control Production Begins	1-Oct-10	27-Sep-10 A	4	N/A
AO-M59790	AOS FAB SLC: Stray Light Control Fab Complete L1	2-Mar-12	13-Jul-12	-94	N/A
AO-M59810	AOS FAB SLC: Stray Light Control Fab Complete H2	27-Apr-12	14-Sep-12	-97	N/A
AO-M59820	AOS FAB SLC: Stray Light Control Fab Complete H1	7-Jun-12	14-Sep-12	-70	N/A
AO-M47110	AOS FAB TMS: TransMon Suspension Production Begins	24-May-11	2-May-11 A	16	N/A
AO-M59	AOS FAB TMS: L1 - TransMon Suspension Fab Complete	21-Jun-12	30-Aug-12	-50	N/A
AO-M59920	AOS FAB TMS: H2 - TransMon Suspension Fab Complete	21-Jun-12	28-Aug-12	-48	N/A
AO-M59960	AOS FAB TMS: H1 - TransMon Suspension Fab Complete	17-Sep-12	21-Nov-12	-49	N/A
AO-M47120	AOS FAB: Initial Alignment (IAS) System Production Begins	26-Jan-11	31-Jan-11 A	-3	N/A
AO-M471XX	AOS FAB: IAS Production Complete - Site 1	7-Oct-11	6-Apr-12	-126	N/A
AO-M471XY	AOS FAB: IAS Production Complete - Site 2	7-Feb-12	6-Apr-12	-42	N/A
AO-M47130	AOS FAB: Optical Lever System Production Begins	23-Sep-10	8-Nov-10 A	-33	N/A
AO-M59900	AOS FAB: Optical Lever Sys. Fab Complete	8-Nov-11	3-Jun-13	-397	N/A
AO-M47150	AOS FAB: Viewports Production Begins	18-Jul-11	9-Jun-11 A	27	N/A
AO-M471XZ	AOS FAB: Viewports Production Complete	28-Mar-12	4-Apr-12	-5	N/A
AO-M47160	AOS FAB: TCS Production Begins for Ring Heater (RH)	10-Nov-10	15-Dec-10 A	-23	N/A
AO-M47180	AOS FAB TCS: Production Begins for HWS	9-Nov-11	1-Aug-11 A	58	N/A
AO-M47190	AOS FAB TCS: Production Begins for CO2P In-Vac	1-Mar-11	1-Mar-11 A	0	N/A
AO-M47210	AOS FAB TCS: Production Begins for CO2P In-Air	16-Nov-12	2-Mar-12	183	N/A
AO-M59800	AOS FAB TCS: Thermal Compensation System Complete L1	18-Apr-12	1-Nov-12	-139	N/A
AO-M59830	AOS FAB TCS: Thermal Compensation System Complete H2	6-Jul-12	23-Jan-13	-132	N/A
AO-M59840	AOS FAB TCS: Thermal Compensation System Complete H1	11-Jan-13	8-Mar-13	-40	N/A
AO-M47170	AOS FAB: Photon Calibrator Production Begins	2-Feb-12	21-Feb-12 A	-12	N/A
AO-M59910	AOS FAB: Photon Calibrator Complete	9-May-13	14-May-13	-2	N/A
AO-M50030	AOS: Auxiliary Optics Subsystem Finish	10-Jan-12	3-Jun-13	-373	N/A

	= Completed activity
	= NSF Reporting Milestones
	= Schedule slippage of 40 days or more. Requires explanation.
	= Schedule slippage resulting in negative total float up to 1 month. Requires explanation.
	= Schedule slippage resulting in negative total float greater than 1 month. Requires immediate mitigating action.

Schedule Change
Negative indicates later than planned
Positive indicates earlier than planned

- **SLC Schedule delays caused by design changes and delayed completion of Final Designs.**

AOS SLC Performance and Variances

Cost Performance to Date: February 2012										
Auxiliary Optics Systems (K$)	**BCWS**	**BCWP**	**ACWP**	**SV**	**CV**	**SPI**	**CPI**	**BAC**	**EAC**	**VAC**
4.07.1 AOS - Management	105	105	138	0	-33	1.00	0.76	202	202	0
4.07.1.2 AOS - Fabrication Management	83	83	28	0	55	1.00	3.00	209	209	0
4.07.4.0 AOS - Fabrication	3,010	3,010	3,186	0	-175	1.00	0.94	4,089	4,089	0
4.07.4.1.1 AOS - Output Faraday Isolator Suspension Assembly	290	282	281	-7	1	0.97	1.00	290	294	(3)
4.07.4.1.2 AOS - Baffels and Beam Dumps	1,099	671	685	-428	-13	0.61	0.98	1,611	1,645	(34)
4.07.4.2.1 AOS - TCS Ring Heater Production	195	167	249	-27	-81	0.86	0.67	195	320	(125)
4.07.4.2.2 AOS - TCS Hartmann Wave-front Sensor Production	206	52	81	-154	-29	0.25	0.64	301	445	(143)
4.07.4.2.3 AOS - TCS CO2 Projection Laser Production	896	277	261	-619	15	0.31	1.06	1,429	1,380	48
4.07.4.2.4 AOS - TCS Phase Camera & Bulls Eye Sensor Production	0	0	0	0	0	0.00	0.00	55	0	55
4.07.4.5 AOS - Transmission Monitor Suspension Fabrication	778	209	215	-568	-5	0.27	0.97	778	819	(41)
4.07.4.5.1 AOS - Transmission Monitor Sus First Article Procure	69	69	69	0	0	1.00	1.00	69	69	0
4.07.4.5.3 AOS - Transmission Monitor Suspension Procurement	260	86	86	-174	0	0.33	0.00	260	260	0
4.07.4.6 AOS - Initial Alignment System (IAS) Procure/Fab	255	247	263	-7	-16	0.97	0.94	255	278	(23)
4.07.4.7 AOS - Optical Lever System (OptLev) Procure/Fab	1,117	876	834	-240	41	0.78	1.05	1,117	1,115	1
4.07.4.8 AOS - Photon Calibrator Fab	109	0	2	-109	-2	0.00	0.00	1,128	847	281
4.07.4.A AOS - Viewports	720	576	577	-143	0	0.00	0.00	720	722	(2)
Performance Measurement Baseline	**9,192**	**6,710**	**6,955**	**(2,476)**	**(242)**	**0.73**	**0.96**	**12,708**	**12,694**	**14**
							72.8%	Scheduled Percent complete		
							52.8%	Actual Percent complete		

- Schedule Variance (SV) is due to delays in completion of Final Designs, First Article rework, design changes, and a material change.
- Cost Variance (CV) is not significant or less than 10%.
- Estimate At Completion (EAC) all less than 3% of the Budget at Completion (BAC).

AOS SLC Contingency Adjustments

- Past Adjustments –
  - ACR-110020 Rescheduled Viewport procurements
  - ACR-110033 revised the SLC and Viewport schedule due to vendor delays
  - ACR-110041 added budget
    - $1,012K to SLC for failed first articles, baffle oxidizing, design changes, external cleaning, tooling, and suspension costs.
    - $136K to Viewports for hardware, clamps, flanges, testing equipment and high power assemblies.

- Anticipated Adjustments for Cost and Schedule - None

Summary of AOS SLC Status

- Working to plan and within the current EAC.
- Efforts being made to expedite deliveries for Install, as needed.
- SLC and Viewports anticipated to complete September 2012.