HEP Project Status Report – April 2019
Large Synoptic Survey Telescope (LSST) Camera

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1. SCORECARD AS OF March 2019

Current CD:	3	Date of Current CD approval:	Aug 27, 2015
Next CD:	4	Forecast/Planned:	Feb 16, 2021
Percent Complete:	91.3%	Baseline:	Mar 31, 2022
ETC:	$13.8	TPC or Cost Range:	$168M
Contingency:	$3.0 (EAC)	Float to CD-4:	273 Days
Cumulative CPI:	0.97	Cumulative SPI:	0.97

2. NEAR-TERM MILESTONES

March 19 Forecast Finish	Activity Name	Float[1]	Comment
15-Apr-19	COMP: IR2 Hx System Ready	22	This was delayed by a few days due to an unexpected leak on the second heat exchanger can during final connection
19-Apr-19	COMP: L1-L2 Post Coat Metrology (Phase 4b)	172	This activity has been delayed due to the minor non-conformance on the L1 lens radius of curvature. It is now expected to be completed in May.
22-Apr-19	START: Filter Exchange System Testing	114	This activity has started earlier than forecasted at the beginning of April. However, an incident on the carousel is expected to delay completion of the testing by about 2 months.
25-Apr-19	COMP: Assembly, Inspection & Verification Testing - Purge Unit	65	This activity has been delayed due to limited resources available to complete the control electronics and software of the test fixture. It is expected to be completed by end of May.
10-May-19	COMP: Cryostat Chamber & I&T Refrigeration System Ready for Integration	3	This is still on track with verification of the remaining 4 cryo circuits expected to start by the end of April
20-May-19	COMP: L1-L2 Assembly - Structure & Mount Phase 4a	235	This activity has been delayed due to the minor non-conformance on the L1 lens radius of curvature. It is now expected to be completed in June.
20-May-19	COMP: Commissioning Camera Shipped to Tucson	134[2]	This activity has been delayed and is expected to occur mid-June due to resource limitations at SLAC in completing the Control Box (quad Box)
30-May-19	START: Science Raft Tower Integration	3	This activity is currently on track with the first raft (RTM20) ready for integration
14-Jun-19	COMP: Last Production RTM (#21) Available for I&T	187	This activity is on track at the current time and is expected to conclude effort at BNL
14-Jun-19	COMP: Camera L3 Lenses Ready for I&T	139	This activity is on track at TSESO
17-Jun-19	COMP: Corner Raft Tower Ready for Integration	3	This activity may be slightly delayed as priority has been given to the science raft refurbishment efforts
28-Jun-19	COMP: Chile Compressor System Ready for Pathfinder	224[2]	This activity is on track if leaks found on the compressor can be addressed by the vendor (MMR)
12-Jul-19	COMP: Exchange System Ready for Integration	56	This will be delayed due to the safety incident at IN2P3
16-Sep-19	COMP: Integration of 9 SR into Cryostat	3	This milestone is on the critical path and currently on track, however there are significant risk both from refrigeration performance and raft cleaning and retrofit that may impact the schedule for this milestone

1) Float to early Camera delivery need date of 11/19/2020.

2) Float to LSST Commissioning

3. STATUS HIGHLIGHTS

General Summary:

A serious injury accident on April 11 has delayed integration of the carousel with the Camera back flange. Carousel work is on hold at LPNHE while the incident is investigated and corrective actions taken. The recovery of the individual is progressing rapidly. Project expects that the incident will impact the carousel schedule by about 2 months; however, the carousel delay is not expected to impact Camera early delivery.

BNL continued the phased-delivery of refurbished Raft Tower Modules (RTMs) to SLAC. By mid-April, five had been delivered to the SLAC IR2 Cleanroom Facility, where the RTMs are put in-queue for re-verification. I&T has found issues with three of the refurbished RTMs which are being resolved, as described in Science Raft section of this report.

In late March, the Corner-Raft team began acceptance-testing of the five Corner Raft Tower Modules (CRTMs) at IR2, Currently the team expects to complete CRTM testing in July, which meets schedule requirements.

At Arizona Optical Systems (AOS), work is underway to attach the L1 lens to the L1-L2 assembly. During an initial check of L1-to-L2 alignment, the Optics team discovered a minor non-conformance on the L1 radius of curvature due to a gravity sag sign error at time of initial acceptance. After investigation, the project has confirmed that the issue can be fully addressed with no performance impact by adjusting the distance between the L1-L2 assembly and the L3 lens.

At Thales SESO (TSESO), integration of the L3 lens with its titanium barrel is in progress. TSESO completed polishing of the i-band filter glass, which was shipped to LLNL for evaluation and test-fitting in its mount. Materion completed coating of the r-band filter and expects to begin qualification testing of the filter soon. Early results have confirmed that the filter coating was successful.

The Filter-Exchange team in France continued construction of production components. The first units of the two loaders and two auto-changers have been completed, and testing is underway.

At IR2, assembly of the Camera body housing resumed after a pause in March to focus on other construction. The Camera body shroud has been delivered. The shroud seals the area between the front of the housing and the L1-L2 assembly support ring. At SLAC, assembly of the production shutter will be delayed due to long lead time for delivery of the shutter blade guides, which are custom-made by a vendor in Japan. The shutter delay will not impact Camera schedule or cost.

I&T completed initial testing of the Bench for Optical Testing (BOT) electro-optical (EO) instrumentation in early April. The testing showed that cold-system and cryo-system refrigeration circuits supported by the first I&T heat-exchanger vacuum canister attached to the BOT meet design requirements. In parallel with the testing, a second I&T heat-exchanger canister was attached to the BOT but kept offline.

The second I&T canister will support the additional cryo-system refrigeration circuits that are required for BOT EO final testing, which I&T expects to begin in early May. Successful completion of final EO testing clears the way for the integration of production RTMs with the cryostat, which I&T expects to begin in the second quarter of 2019.

The last of the four I&T refrigeration cabinets successfully completed final testing and was installed at IR2 for operation with the second heat-exchanger canister. Work on refrigeration cabinets for the on-telescope system (also called the telescope mount assembly or TMA) is progressing, although some of the compressors had to be sent back to the vendor (MMR) to address minor leaks that were found during testing at SLAC.

I&T began to assemble the Camera integration stand at IR2, and procurement of Camera sub-assembly fixtures is well underway. Also, I&T continues to support about half of the RTM refurbishment activities. UC-Davis and SLAC teams trained by BNL are qualified to disassemble and clean rafts at SLAC.

In late March at IR2, the ComCam team integrated a raft with the ComCam Dewar. BNL had provided the commissioning raft, ComRaft, as a schedule-mitigation RTM to be used for ComCam testing until one of the two ETUs is available from I&T for use with ComCam. The ComCam team expects to complete testing with ComRaft by end of April. Currently, the ComCam pre-ship review is scheduled to be held in July, but the ComCam team is working to accelerate the schedule to allow a May review.

Status by Camera subsystem:

- **Systems Integration.** The Systems Integration team continued work on verification and test plans and acceptance reviews for various Camera subsystems.
- **Sensors.**
  ITL and e2v have completed and delivered all sensors per their contracts.
- **Science Raft.** BNL continued the phased-delivery of refurbished RTMs to SLAC (Figure 1). Thus far, five have been delivered to IR2. The phased-delivery is expected to continue into the third quarter of 2019. At SLAC, I&T will re-verify refurbished RTMs and prepare them for integration within the cryostat.

  RTM1 was cleaned and refurbished at BNL and shipped to SLAC, where RTM1 was re-verified for EO performance. All channels that were previously identified as dead channels and covering four different sensors were recovered and performed as expected; however, a single sensor has developed three "glowing" segments out of 16 that were previously functioning properly prior to the cleaning and retrofit. Investigation by the project concluded that an ESD event during re-assembly is the likely cause of the glow. The project is reviewing potential corrective action to prevent this from recurring and has now planned to replace the sensor with a spare.

  RTM11 has also been cleaned, refurbished, and received at SLAC. So far, all channels are functioning, however, the read noise unexpectedly increases below -70C. Investigation has identified a ground loop by an unexpected short-circuit between a thermal strap and the thermal shield which is likely the cause of the increase noise. The team plans to re-seat the thermal strap to remove the short circuit by the end of April.

  Also, one of the channels on RTM 20 has exhibited a low gain, which could have been a pre-cursor to a glow. The team has now confirmed that it is not a glow but simply an open circuit (effectively a non-functioning channel, however, well within the required error budget). The raft has completed full EO testing and been accepted as is for integration into the cryostat starting mid-May.

  RTM17 and RTM22, recently received from BNL, have been re-tested warm at SLAC and have showed no issues so far. The final cold EO testing planned by the end of April is expected to confirm that these rafts are ready for integration into the cryostat.

  Following is a table that summarizes current status of each RTM and describes the four mitigation plans that apply to them.

  Table 1: Summary of RTM status as of April 23, 2019 (bold and underlined text indicates updates since the last report).

RTM	Sensors	Location	Original State[1]	Plan[2]	Current Status
RTM1	ITL	BNL	4 dead channels	B	Refurbished at BNL, dead channels recovered; shipped to and received at SLAC. Testing started and showed 3 glowing channels on a single sensor caused by an ESD event. Raft has been dis-assembled and **has been shipped to BNL for replacement by end of April 2019**
RTM2	e2v	BNL	1 dead channel	C	Dis-assembled at SLAC. **Shipped to BNL**
RTM3	e2v	BNL	0 dead channels	C	Dis-assembled at SLAC. **Shipped to BNL**
RTM4	e2v	SLAC	1 dead channel	C	Dis-assembled at SLAC. Waiting to be shipped to BNL
RTM5	e2v	SLAC	0 dead channels	C	Dis-assembled at SLAC. Waiting to be shipped to BNL
RTM6	e2v	BNL	Several shorts	A	Disassembled at BNL and **cleaning completed and sensor re-assembled. Metrology test under way.**

RTM7	e2v	SLAC	0 dead channels	C	Pending start of dis-assembly.
RTM8	ITL	SLAC	1 dead channel	D	Disassembled at SLAC and waiting to be cleaned.
RTM9	e2v	BNL	1 glowing sensor (will be removed)	A	Disassembled at BNL. **Sensor were cleaned and reconstruction is under way (one pre-existing missing channel remains)**
RTM10	ITL	BNL	3 high-noise sensors	A	**Refurbished at BNL, dead channels recovered. Expected to ship to SLAC 4/26**
RTM11	ITL	SLAC	3 dead channels	B	Refurbished at BNL, dead channels recovered; shipped to and received at SLAC. Raft has showed high noise when cold **tracked to date to a ground loop from a short between the thermal strap and the shroud. Raft is being updated.**
RTM12	e2v	SLAC	0 dead channels	C	Pending start of dis-assembly.
RTM13	e2v	SLAC	0 dead channels	C	Pending start of dis-assembly.
RTM14	ITL	SLAC	1 dead channel	D	Disassembled at SLAC and waiting to be cleaned.
RTM15	ITL	SLAC	1 dead channel	D	Pending start of dis-assembly.
RTM16	e2v	SLAC	0 dead channels	C	Pending start of dis-assembly.
RTM17	e2v	SLAC	0 dead channels (complete, on hold)	B	Refurbished at BNL, dead channels recovered; shipped to and received at SLAC. **Warm aliveness test shows all channels functioning within nominal parameters.**
RTM18	ITL	SLAC	0 dead channels	D	Pending start of dis-assembly.
RTM19	ITL	BNL	1 high CTE sensor (will be removed)	A	**Refurbished at BNL, dead channels recovered, one sensor exhibited a glow that can be traced back to the fall of 2018. Sensor has been replaced.**
RTM20	ITL	SLAC	0 dead channels (complete, on hold)	B	Process completed at BNL, shipped to and received at SLAC. One channel was suspect. **Now tracked to be a disconnected channel (not a glow). Has been accepted as is for integration into the cryostat.**
RTM21	e2v	BNL	0 dead channels (complete, on hold)	B	**Refurbished at BNL. Expected to ship to SLAC 4/26**
RTM22	e2v	SLAC	Incomplete (not constructed yet)	A	Completed at BNL, shipped to and received at SLAC. **Warm aliveness test shows all channels functioning within nominal parameters.**

1) State prior to channel-loss mitigation.
2) Migration plans A through D:
A. RTM to be disassembled, cleaned, retrofitted, re-assembled and qualified at BNL and then re-verified at SLAC: Applies: to 1) RTMs that were returned to BNL that require sensor replacement due to permanent damage or performance issues; and 2) incomplete RTMs at BNL that are currently on hold. There are five RTMs in this category, all of which will be re-verified at SLAC.
B. RTM to be disassembled, cleaned, retrofitted, re-assembled at BNL, and then re-verified at SLAC: Applies to 1) RTMs that were returned to BNL that do NOT require sensor replacement; and 2) completed/tested RTMs at BNL that were never shipped to SLAC and are currently on hold at BNL. There are six RTMs in this category, all of which will be re-verified at SLAC.
C. (e2v only) RTM to be disassembled at SLAC and the RSA will be shipped to BNL for cleaning and retrofitting, and then returned to SLAC for re-assembly and re-verification at SLAC: Applies to e2v-based RTMs currently at SLAC (e2v-based RTMs require sensor removal due to limited access to the wire bonds while installed on the RSA). There are eight RTMs in this category, all of which will be re-verified at SLAC.
D. (ITL only) RTM to be disassembled, cleaned, retrofitted, reassembled and re-verified at SLAC: Applies to ITL-based RTMs already at SLAC. There are four RTMs in this category.

- **Corner Raft.** The five Corner-Raft Tower Modules (CRTMs) required by the project were constructed in late 2018. Four of the CRTMs are for the focal plane, and the fifth will be used as a spare. In March, the Corner Raft team began acceptance-testing of the CRTMs at IR2. The testing had been delayed earlier this year,

because key personnel were diverted to work on the science-raft channel-loss issue. Currently, the team expects to complete CRTM testing in July.

- **Optics.** Arizona Optical Systems (AOS) completed the L1 lens and work is underway to attach it to the L1-L2 assembly (Figure 2). L2 was attached last summer. During an initial check of L1-L2 alignment, the Optics team discovered a small non-conformance on the L1 radius of curvature due to a gravity sag sign error at time of initial acceptance. After investigation, the project has confirmed that the issue can be fully addressed with no performance impact by adjusting the distance between the L1-L2 assembly and the L3 lens.

  Thales SESO (TSESO) completed final inspection of the L3 lens following Broadband Anti-Reflective (BBAR) coating (Figure 3). The lens meets project requirements. TSESO received the L3 barrel from the painting vendor and has begun the process of integration of L3 with the barrel, which is going well (Figures 4 and 5).The barrel will surround L3 and provide attachment to the cryostat housing.

  TSESO completed polishing of the i-band filter glass, which has been shipped to LLNL for evaluation and test-fitting in its mount. TSESO expects to finish z-band polishing later this month. Processing of the u-band, g-band, and y-band continued at TSESO. Materion, the filter-coating vendor, completed coating of the r-band filter and expects to begin qualification testing of the filter soon. Early results have confirmed that the filter-coating was successful.

- **Filter Exchange**. The Filter-Exchange team in France continued construction of production components. As reported, CPPM completed the assembly of the first of two auto-changers, and testing of the first unit is well-underway (Figures 6 and 7). CPPM also completed procurement of parts for the second unit.

  LPNHE was on-track to complete integration of the production carousel with the Camera back flange in the second quarter of 2019 (Figure 8); however, there was an injury incident at LPNHE during carousel testing on April 11. The incident involved one person who required surgery on their arm.

- Work is currently on hold at LPNHE while CNRS (governing institution) is investigating and identifying lessons learned and corrective action. The LSST Camera team is also planning a visit on May 22-24, 2019 to review implementation of safety corrective action and the plan forward; this is necessary, since similar verification work is planned at SLAC after delivery of the carousel from LPNHE. The incident is expected to affect carousel schedule by about 2 months; although this delay is not expected to impact Camera early delivery at this time, any delays beyond the estimated 2 months will place this element on or near CP.

  LPSC completed assembly of the first of two loaders and testing is well-underway (Figure 9). LPSC is nearly done procuring parts for the second unit.

- **Camera Body and Mechanisms.** At SLAC, bonding of the Camera body housing is in progress at IR2 and expected to be completed by late April. The vendor completed fabrication of the Camera body shroud and delivered the shroud to SLAC. Procedures for assembly of parts to the shroud have been released.

  As reported, assembly of the production shutter was started at SLAC, but the forecasted completion date was pushed back about a month due to long-lead time for delivery of the shutter-blade linear guides, which are custom-made by a vendor in Japan. The shutter delay will not impact Camera schedule or cost.

  The production shutter blades and garage plates are at the painting vendor. The two garage plates are flat structures that surround the blades, providing a well-defined aperture for the shutter.

- **Cryostat and Refrigeration.**
  - **Utility Trunk**: The project worked to complete five feedthroughs for power cabling from the utility trunk to the cryostat (four production feedthroughs plus a spare). As of mid-April, wiring of four feedthroughs was completed, and three feedthroughs have completed RGA testing. The team is on-track to complete and install the four feedthroughs required for final BOT EO testing by late April.
  - **Refrigeration:** Initial EO testing demonstrated that the two cold-system and two cryo-system circuits

supported by the first I&T canister meet design and operation requirements. In parallel with this testing, the second I&T heat-exchanger canister, which will support four cryo-system circuits, was attached to the top of the BOT. Testing of the second canister is underway.

As reported, the last of the four I&T refrigeration cabinets completed final testing and was installed at IR2 in late March. The team discovered a number of small refrigerant leaks, which are expected to be fixed soon. Currently, the cabinet is on track to support final EO testing by late April.

Work on refrigeration cabinets for the on-telescope system is progressing; however, as reported last month, some compressors had to be returned to the vendor (MMR) to address leaks that were detected during testing at SLAC.

SLAC provided the heat exchanger vendor with revised drawings for improved manufacturability of parts for heat-exchangers for the on-telescope (TMA) refrigeration system. The contract modification was approved, and work is expected to begin shortly. Delivery is expected in July 2019.

All parts for Pathfinder heat exchangers are at SLAC, and assembly is underway. Construction of the vacuum vessel that will contain the Pathfinder heat exchangers has started at the vendor and is expected to be completed by late April.

Following is a table that summarizes current status of refrigeration components.

Table 2: Summary of Refrigeration Status as of April 23, 2019.

Component(s)	System	Circuits	Status	Location
Evaporator	Camera Cryostat	2 Cold circuits	**Tested successfully. Some of the RTD thermal sensors appear to be coming loose from thermal cycling and will need to be checked.**	SLAC
		6 Cryo circuits	**Two of the four circuits were tested successfully**	SLAC
	Pathfinder Chamber	2 Cold circuits	Chamber is under final design.	Not built yet
		2 Cryo circuits	Chamber is under final design.	Not built yet
Heat Exchangers	I&T (to become Chile maintenance system)	Vacuum Can 1: 2 Cold and 2 Cryo circuits	**Operating in SLAC clean room successfully.**	SLAC
		Vacuum Can 2: 4 Cryo circuits	**Assembly completed and installation on cryostat completed.**	SLAC
	Pathfinder	Vacuum Can 1: 2 Cold and 2 Cryo circuits	All parts from vendor in hand. Assembly underway. One coil is being repaired.	SLAC
	On Telescope (Chile)	Vacuum Can 1: 2 Cold and 2 Cryo circuits	Parts received at Eden. Manufacturability design improvements provided to vendor. Contract modification under way.	Eden
		Vacuum Can 2: 4 Cryo circuits	Parts received at Eden. Manufacturability design improvements provided to vendor. Contract modification under way.	Eden
Compressor Cabinets	&T (to become Chile maintenance system)	2 Cold cabinets, each supporting 1 Cold circuit	**The two Cold cabinets are operating successfully at SLAC in IR2. There are several minor leaks that will need retrofitting during the next shutdown.**	SLAC

		2 Cryo cabinets, each supporting 3 Cryo circuits	**<u>One Cryo cabinet is operating successfully at SLAC in IR2. There are several minor leaks that will need retrofitting during the next shutdown. The second Cryo cabinet under final testing at SLAC before delivery to the clean room.</u>**	SLAC
	On Telescope (to be used in Chile with Pathfinder first)	2 Cold cabinets, each supporting 1 Cold circuit	Parts on hand. Being assembled at SLAC.	SLAC
		2 Cryo cabinets, each supporting 3 Cryo circuits	Parts on hand. Some compressors are being repaired at MMR vendor due to some leaks. Being assembled at SLAC.	SLAC

- **Integration and Test (I&T).** I&T continued activities related to RTM channel-loss mitigations and related to preparations for RTM integration using the BOT. I&T also continued with preparation of the Camera integration stand and with procurement of fixtures to be used for positioning Camera subassemblies during construction.

  I&T successfully completed qualification testing of the cryostat vacuum system in March. Using a single heat exchanger canister mounted on the BOT, I&T completed initial testing of BOT EO instrumentation in early April. The single canister was sufficient to cool the two engineering test unit (ETU) rafts inside the cryostat, operating under the control of Computer Control System (CCS) software that is integrated with the BOT. Figure 10 shows the current BOT operations area at IR2.

  During initial EO testing, the second I&T heat-exchanger canister was attached to the top of the BOT but was not online. The second canister is required for final EO testing, which will establish BOT readiness for integration of production RTMs. As stated earlier, I&T expects to begin final EO testing by late April or early May. I&T plans to begin integration of production RTMs in the second quarter of 2019.

  In mid-April, the cryostat was opened for the installation of Optical Translation Modules (OTMs) and feedthrough cabling. Those activities, and the testing of cryo-circuits supported by the second heat-exchanger canister, are set to continue until late April. Some minor leaks were discovered on the power feedthroughs and have been addressed impacting slightly the schedule from the few days of delays required to resolve the issue.

  Assembly of the Camera integration stand is underway at IR2 (Figure 11). The stand will cradle the Camera during construction. Piers for the two sides of the stand were leveled and holes were drilled for attachment to the floor. The cradle that sits on the main weldment was assembled outside IR2 and moved into place. An interface plate that will attach the cradle to the Camera rotator was fit-checked and sent for final modifications.

  Procurement of sub-assembly fixtures continued. Those fixtures include: the cryostat support stand, cryostat c-hook lift fixture, and Camera saddle stand (to cradle the Camera during storage and shipment).

  I&T continues to support about half of the RTM channel-loss mitigation activities described in the Science Raft section of this report. UC-Davis and SLAC teams trained by BNL are qualified to disassemble and clean rafts at SLAC. Table 1 contains current status of RTMs set to undergo processing at SLAC.

  As RTMs are cleaned, upgraded and reassembled, they will be delivered to I&T for reverification at IR2. Thus far, five RTMs have been delivered to I&T and are undergoing re-verification or are in queue for it.

- **Commissioning Camera (ComCam).** As stated earlier, the team installed ComRaft in preparation for final testing of the ComCam cryostat configuration. BNL has provided ComRaft on an interim basis for ComCam testing. The final ComCam raft is expected to be one of the ETUs currently reserved by I&T for BOT testing.

ComCam testing with ComRaft is expected to be finished by late April. Currently, the ComCam pre-ship review is scheduled to be held in July, but the team is trying to tighten the schedule to allow a May review date.

- **Commissioning.** Currently, the MIE project forecasts that the Pathfinder compressor cabinets will not be available until May 2019 at the earliest. Storage tanks for Pathfinder cryo-system refrigeration have been filled at SLAC and prepared for shipment to the summit.

  Also at SLAC, the cold-system heat exchangers are cleaned and work has started on the cryo-system heat exchangers. The one cryo coil needing repair was fixed successfully by SLAC technicians. The Pathfinder heat loads have been designed and are in production at SLAC. As stated earlier, construction of the vacuum vessel that will contain the heat exchangers has started.

4. ISSUES

- The injury incident related to the work on carousel in France is being investigated. The lessons learned will be applied at SLAC since similar verification work is planned at IR2 after delivery of the carousel from LPNHE. The incident is expected to affect carousel schedule by about 2 months; although this delay is not expected to impact Camera early delivery at this time, any delays beyond 2 months will place this element on or near CP.
- The impact of metallic particulate contamination leading to loss and potential damage of some sensor channel has strained the level of contingency on the project. While significant progress has been made in refurbishing the rafts, there is significant risk related to the additional handling of the rafts as evidenced by several small issues discovered on recently refurbished rafts.
- The read-noise issue with ITL RTMs remains a concern as is the appearance of glows on some sensors, which is not fully understood yet. The project has reviewed impacts on science requirements allowing the use of some sensors that have degraded performance, which is reducing the risk of not having enough sensors available. The risk will remain high until performance-testing is completed at the integrated Camera level.
- Manufacturing issues with the on-telescope heat exchangers still remains even though significant effort has been invested in simplifying the design. Refrigeration performance remains a risk as well, although it is reduced based on the recent successes demonstrated with the first heat exchanger canister.
- The vacuum-system remains a technical risk regarding initial pump down time, capacity and lifetime based on early results with the cryostat. A tiger team was assembled and has completed the plan to address these issues. Early results of full cryostat pumping in February are reducing this risk significantly as the new pump down procedure is now estimated to take 8 days to reach acceptable pressure based on early measurement as opposed to 3 weeks from the previous measurements.

5. COST AND SCHEDULE SUMMARY ($M)

	WBS	BAC	CTG	EAC	Contingency	Actuals
TEC	3	$143.1	$13.8	$147.6	$3.0	$133.8
Management	3.01	$12.2	$1.9	$11.8		$9.9
Systems Integration	3.02	$7.1	$1.1	$6.8		$5.7
Science Sensors	3.03	$30.0	$0.0	$29.7		$29.7
Science and Corner Raft System	3.04	$22.5	$0.7	$22.3		$21.6
Optics	3.05	$26.5	$4.7	$26.5		$21.8
Camera Body, Mechanisms, Cryostat	3.06	$20.3	$1.1	$24.1		$23.0
CCS, DAQ, Auxiliary Electronics	3.07	$12.0	$1.0	$13.6		$12.6
Integration and Test	3.08	$12.5	$3.3	$12.8		$9.5
OPC	3	$17.2	$0.0	$17.4	$0.0	$17.4
Management	3.01	$3.0	$0.0	$3.0		$3.0
Systems Integration	3.02	$2.2	$0.0	$2.2		$2.2
Science Sensors	3.03	$4.0	$0.0	$4.1		$4.1
Science and Corner Raft System	3.04	$2.1	$0.0	$2.1		$2.1
Optics	3.05	$1.6	$0.0	$1.6		$1.6
Camera Body, Mechanisms, Cryostat	3.06	$2.9	$0.0	$3.0		$3.0
CCS, DAQ, Auxiliary Electronics	3.07	$1.1	$0.0	$1.1		$1.1
Integration and Test	3.08	$0.3	$0.0	$0.3		$0.3
TEC+OPC	3	$160.3	$13.8	$165.0	$3.0	$151.2
TPC	3	$168.0		$168.0		

[1)] Camera level 3 designation based on LSST Project WBS.

Schedule summary:

Level	Milestone	Actual & **Forecast**	Baseline Finish
L1	COMP: CD-0, Approve Mission Need	20-Jun-11 A	06/20/11
L1	COMP: CD-1, Approve Alternative selection and Cost Range	11-Apr-12 A	04/11/12
L1	COMP: CD-3a, Approve Start Long Lead Procurements	05-Jun-14 A	06/05/14
L1	COMP: CD-2, Approve Performance Baseline	07-Jan-15 A	01/30/15
L1	COMP: CD-3, Approve Start of Construction	27-Aug-15 A	01/29/16
L1	COMP: CD-4, Approve Project Completion	02/16/21	03/31/22
L2	COMP: Conceptual Design Complete (Ready for CD-1)	30-Nov-11 A	11/30/11
L2	COMP: Prototype Science Sensors Received	03-Jan-12 A	01/03/12
L2	COMP: Vertical Slice Test - Phase 1	16-May-13 A	05/16/13
L2	COMP: Sensor Final Design Complete (Ready for CD-3a)	31-Mar-14 A	03/31/14
L2	COMP: First Article Sensor Contract Placed	24-Apr-14 A	04/24/14
L2	COMP: Performance Baseline Established (Ready for CD-2)	16-Oct-14 A	10/16/14
L2	START: ASIC production (IN2P3)	25-May-15 A	03/31/16
L2	COMP: Award L3 Assembly Phase 1 Contract	08-Jun-15 A	07/31/15
L2	COMP: Camera Design Complete (Ready for CD-3)	12-Jun-15 A	09/30/15
L2	COMP: L1-L2 Assembly Phase 2 FDR	30-Oct-15 A	02/29/16
L2	COMP: First Sensor Tested	27-Jan-16 A	02/29/16
L2	COMP: First article 2Kx4K Wavefront Sensor (Phase 1)	16-May-16 A	12/16/16
L2	COMP: Award Sensor Lot 2	02-Aug-16 A	08/31/16
L2	COMP: First RTM Ready for Integration	26-May-17 A	05/31/17
L2	COMP: Sensor Production is 50% complete (end of lot 2)	29-Sep-17 A	02/28/18
L2	COMP: L1 & L2 Pre-Coating Metrology (Phase 4b)	16-Feb-18 A	02/28/18
L2	COMP: Sensor Production Complete	16-Nov-18 A	03/29/19
L2	COMP: Cryostat Chamber & I&T Refrigeration System Ready for Integration	05/10/19	12/13/18
L2	COMP: Commissioning Camera Ready to Ship for Testing	05/20/19	05/31/19
L2	COMP: L3 Assembly Ready for Integration	06/14/19	04/30/19
L2	COMP: Filter Exchange System Ready for Integration (IN2P3)	07/12/19	01/31/19
L2	COMP: 1st Filter Coated and Ready for Integration	08/16/19	08/30/19
L2	COMP: L1/L2 Assembly Ready for Integration	08/19/19	10/31/19
L2	COMP: Early Hardware & Software Ready for Summit	10/22/19	10/31/19
L2	COMP: Loaded Cryostat Ready for Integration	12/18/19	02/28/20
L2	COMP: Camera Fully Integrated & Ready for Verification Testing	06/18/20	08/31/20
L2	COMP: PSR/ORR - Camera Pre-Ship/Operations Readiness Review Complete	11/16/20	02/26/21
L2	COMP: KPPs achieved (Camera Readiness Review, Ready for CD-4)	11/16/20	10/29/21

6. KPP status as of April 23, 2019

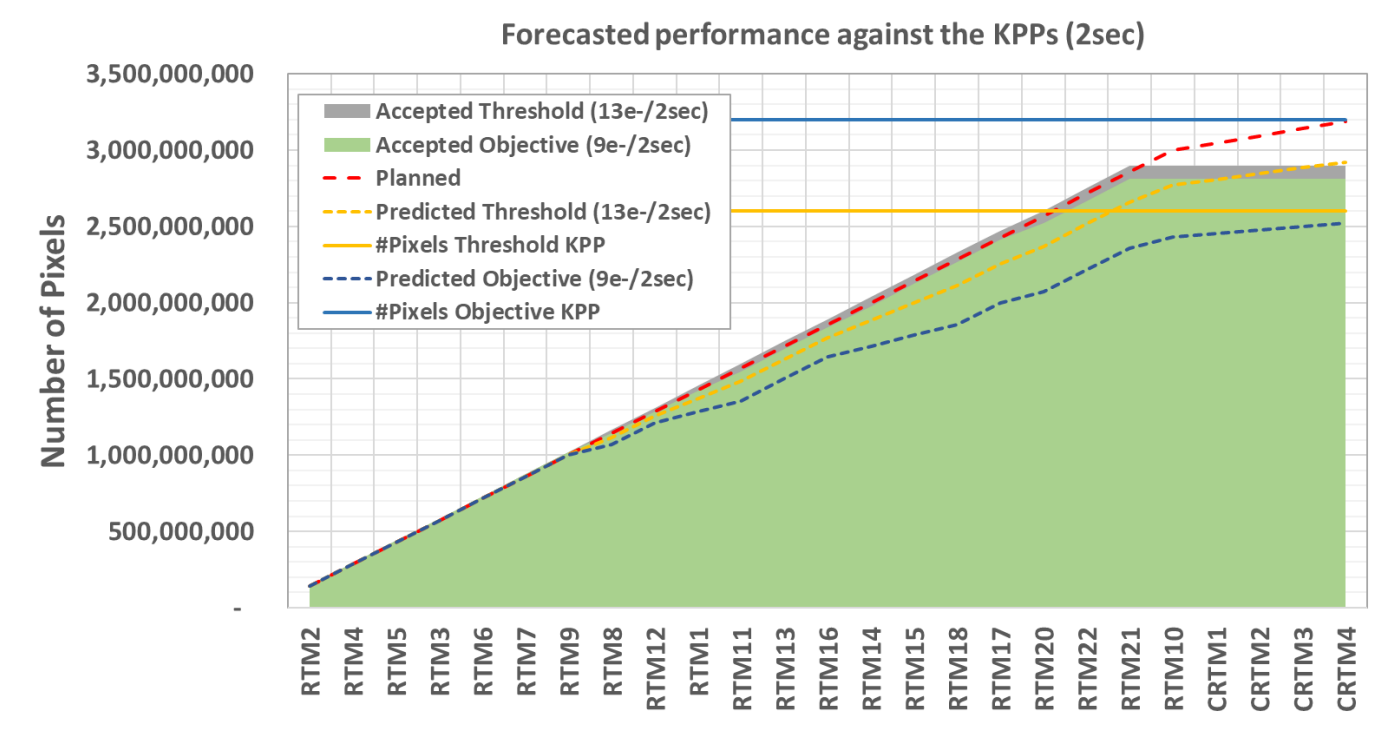

Figure 1: Progress against the KPP for raft accepted at BNL regardless of channel loss retrofit. Includes the new RTM22 and RTM21

7. FIGURES

Figure 1: Receiving RTM17 and RTMN22 at the SLAC IR2 Cleanroom Facility in early April. Near the door, the top half of one container was removed, showing the bell-jar that holds one RTM during shipment. At right, a second container sits unopened on a pallet. Thus far, BNL has delivered five refurbished RTMs to I&T for re-verification.

Figure 2: Test fit of the L1 lens within the L1-L2 lens assembly. During initial testing, the Optics team discovered a small non-conformance in the L1 lens radius of curvature. After investigation, the project believes the issue can be fully addressed with no performance impact by adjusting the distance between the L1-L2 assembly and the L3 lens.

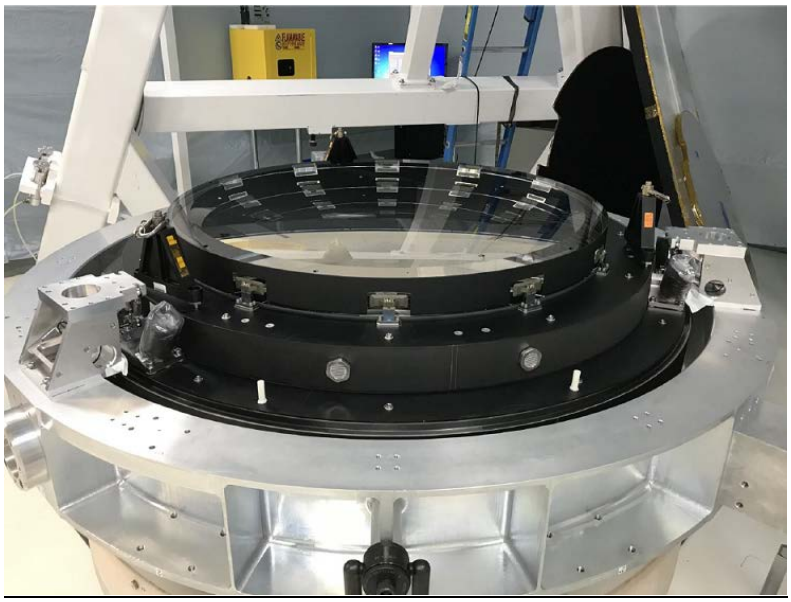

Figure 3: REOSC successively completed Broadband Anti-Reflective (BBAR) coating of the L3 lens and returned L3 to Thales SESO (TSESO) for inspection. The Optics team determined the lens meets project requirements.

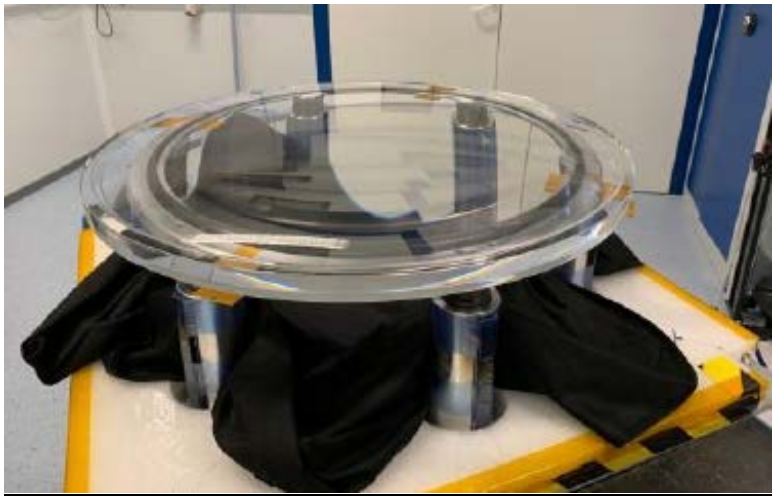

Figure 4: The back side of the L3 titanium barrel at TSESO after delivery from the painting vendor. The back side will face the cryostat. The barrel will surround L3 and provide attachment to the cryostat housing.

Figure 5: Early stages of integration of the L3 lens with its barrel. Here, the front side of the barrel is shown. The barrel is also called the cryostat front flange.

Figure 6: At CPPM, testing for the first unit auto-changer on its standalone test bench. Here the auto-changer is oriented at 45 degrees to the horizontal. On the Camera, the auto-changer can be used to swap a filter from online position in front of the L3 lens to one of the five storage positions on the filter carousel.

Figure 7: The first-unit auto-changer tested under heavy load, which is provided by a filter mass simulator (dummy filter) with weights attached.

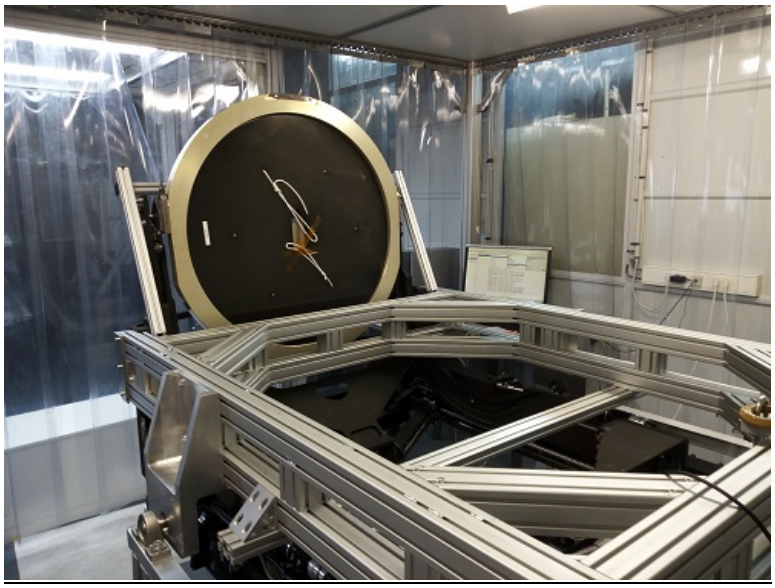

Figure 8: Integration of the carousel rotating mechanism with the Camera back flange at LPNHE. As shown, the two units are tightly integrated, with carousel components installed within the back flange casting (gold-colored structure). Work is currently on hold due to an injury safety incident.

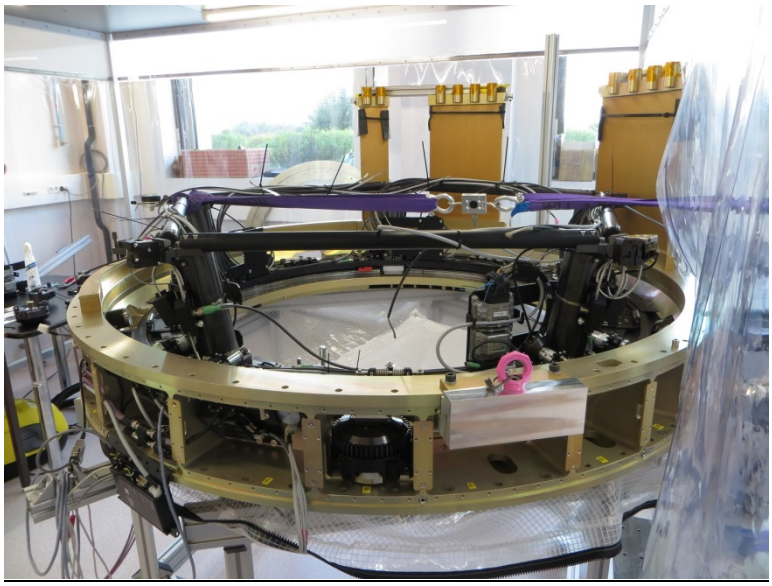

Figure 9: The first unit production loader during testing at LPSC. Here the loader drive mechanism has fully retracted a dummy filter into the loader enclosure. Either of the two manual filter loaders can be used to install a filter into the auto-changer on-Camera or to remove a filter from the auto-changer for storage off-Camera.

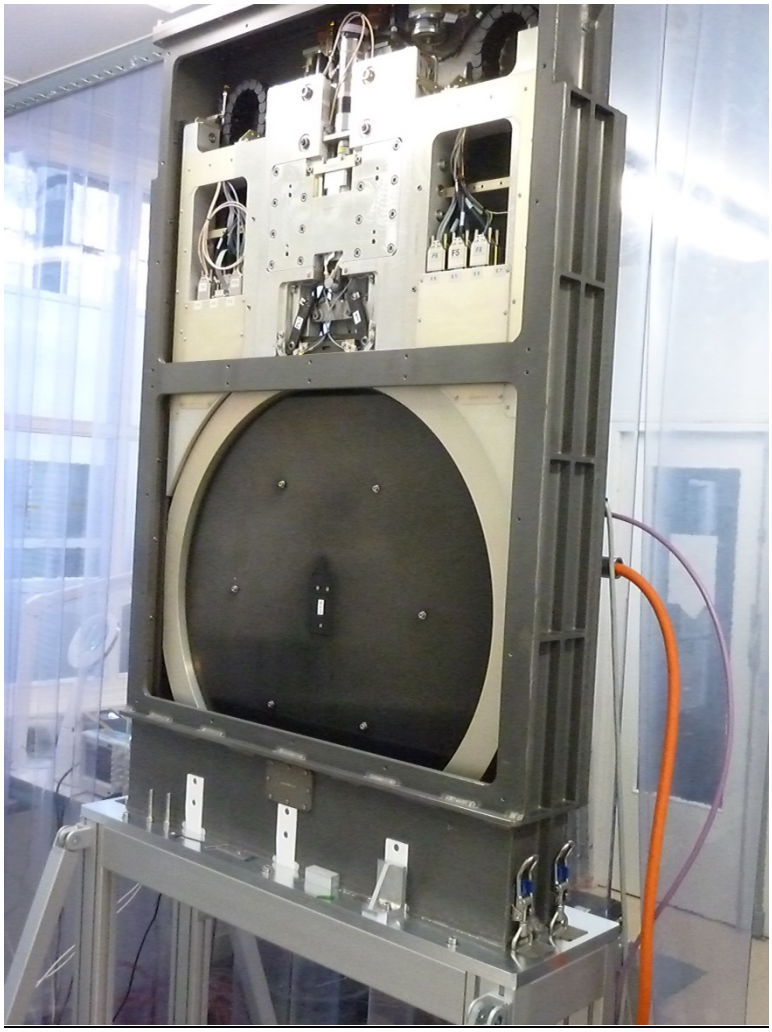

Figure 10: A recent view facing the north corner in the main (high bay) area of SLAC IR2. The Bench for Optical Testing (BOT) is in the foreground, behind the work platform. The two I&T heat-exchanger canisters installed on the BOT are identified with callouts. The first canister contains heat-exchangers that support cooling of two cold-system and two cryo-system refrigeration circuits. The second canister contains heat exchangers that support an additional four cryo-system circuits. The two cold-system circuits cool raft electronics, and the six cryo-system circuits cool the Camera focal plane.

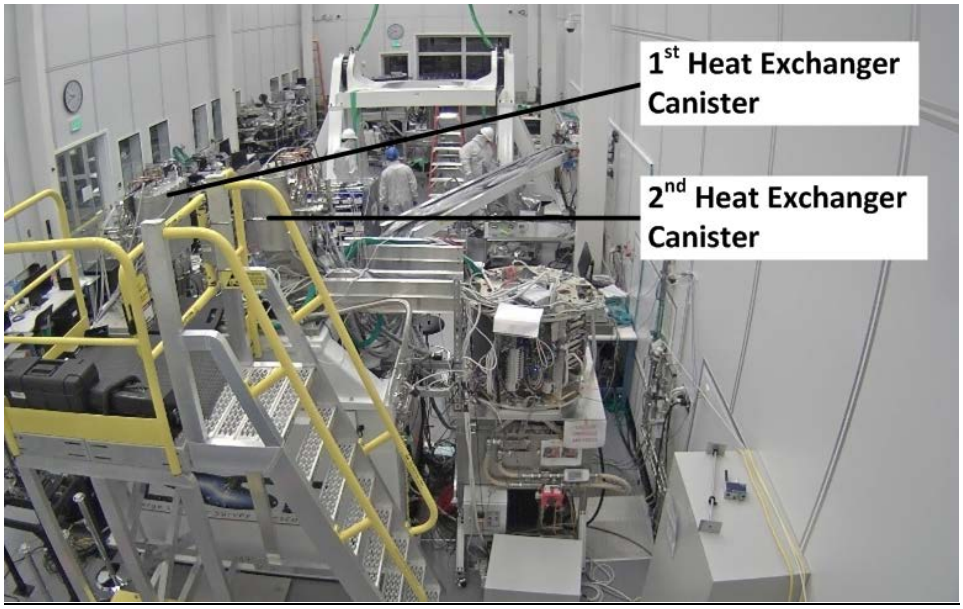

Figure 11: A recent view of the IR2 main area facing south (opposite the view in Figure 10). In the foreground, the cryostat housing sits on an assembly work bench. Beyond that, technicians work on assembly of the Camera integration stand. The integration stand will cradle the Camera during construction.