Keck Adaptive Optics Note 861

Near-Infrared Tip-Tilt Sensor Systems Engineering Management Plan
at the Preliminary Design Review

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1. Introduction

This document is written in support of the NSF ATI-funded near-infrared (NIR) tip-tilt sensor (TTS) project. The purpose of this document is to define the systems engineering management plan (SEMP) for the completion of the NIR TTS system and its implementation with the Keck I LGS AO system. This document represents an update to the project plan in the original ATI proposal and the SEMP presented at the system design review (SDR; KAON 839).

2. Organization Structure and Lead Personnel

The organization chart for the project, provided in the NSF proposal, is shown in Figure 1. Table 4 provides descriptions of the project staff. Wizinowich had been acting as project manager through the preliminary design phase of this project in order to allow Stalcup to focus on the K1 LGS free space transport project. He will continue in this role. Chris Neyman was added to the project team for the preliminary design phase to provide systems engineering support and to help define the operations software tools. He will continue in these roles. Andrew Cooper replaced Ed Wetherell during the preliminary design phase, and he will need to continue this role during the detailed design phase.

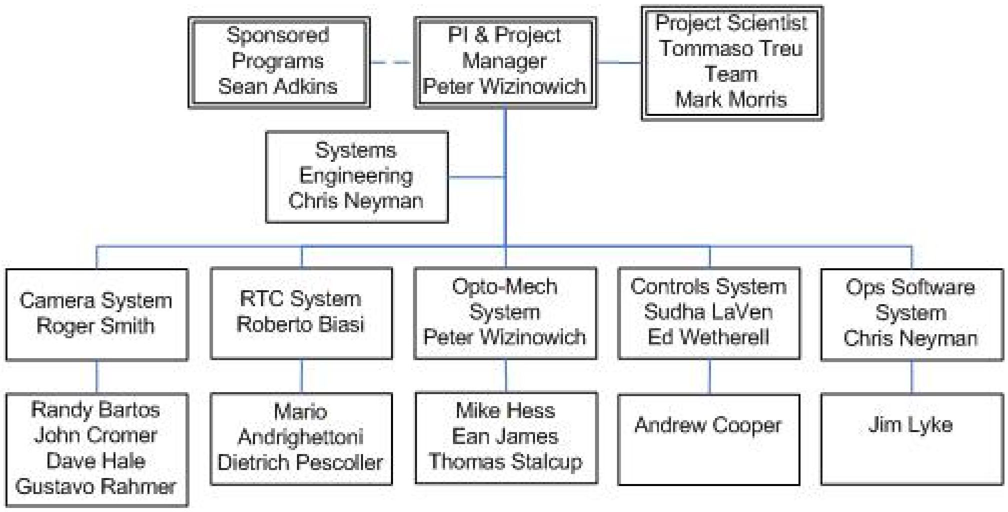


Figure 1: Project Organization

Table 1: Project Staff

Position	Name	Notes
P.I., Project Manager & Opto-Mechanical Lead	Peter Wizinowich	As PI & AO project manager Wizinowich is responsible for the overall project success in coordination with other WMKO activities. Responsible for managing the engineering team & project to meet the budget and schedule. Responsible for the design & implementation of the opto-mechanical system, plus the optical design of the camera system.
Project Scientist	Tommaso Treu	Leads the management of the science requirements for the upgrade and oversees the performance characterization phase of the project.
Camera System Lead	Roger Smith	Responsible for the design and delivery of the NIR sensor, including readout mode validation and lab performance testing.
Systems Engineer + Operations Software Lead	Chris Neyman	Manages the design process to ensure proper design choices and maintains the performance budgets. Responsible for the overall integration of the system from sub-system acceptance through lab, telescope I&T & handover. Responsible for the design and implementation of the operations software tools.
RTC System Lead	Roberto Biasi	Responsible for the design and implementation of the RTC system per the SOW (KAON 824).
Controls Software Lead	Sudha LaVen	Responsible for the design & implementation of the controls software. Also oversight responsibility for all software & the software interfaces.
Controls Hardware Lead	Ed Wetherell A. Cooper	Responsible for the design & implementation of the controls hardware. Also oversight responsibility for all electronics & the electrical interfaces. Responsibility will switch from Andrew Cooper during the design to Ed Wetherell during the implementation.

WMKO's normal management process will provide oversight for this project. This includes regular status reports to WMKO's management and Science Steering Committee. WMKO's Office of Sponsored Programs will monitor project compliance with NSF terms and conditions, including timely reporting. Regular project meetings will be held to manage activities, discuss progress and address problems.

3. Product Breakdown Structure

The Product Breakdown Structure (PBS) is shown in Table 2. The five major subsystems are shown at level 1 and their major components at level 2. A quick summary of the 5 major subsystems of the PBS and their key components is provided in Figure 2. There is one change since the SDR: the field lens and fold mirror and the interface plate between the camera and the focus stage have been transferred from the opto-mechanical system to the camera system.

Table 2: Product breakdown structure

PBS Level 1	Level 2	Level 3
Camera System	External opto-mechanics	Kinematic interface plate
		External optics cylinder
		Field Lens & Mount
		Fold Mirror & Mount
	Camera	Camera Opto-mechanics
		Filter Change Mechanism
		Filter Stage Motor, Limit Switches & Cable
		Dewar Cryostat
		Detector
		Heaters/Thermistors
	Readout Electronics	ARC Timing Board
		Video Card
		Interface to Dewar
		Interface to Host Computer
		Interface to RTC
	Housekeeping Electronics	Housekeeping Interface Board
		Temperature Controller/Sensor
		Interface to Host Computer
	External Motion Control	Stepper Motor Driver
		Interface to Host Computer
	External Cryo System	CryoTiger
		Interface to Dewar
	External Vacuum System	Ion Pump
		Interface to Dewar
	Host Computer	Computer
		Readout Control Software
		Housekeeping Control Software
		Motion Control Software
		Keyword Interface
Real-Time Control System	Microgate HW Mods	Camera Interface
	Microgate Software Modifications	Camera Interface & Readout
		Wavefront Controller Interface Mods
		Wavefront Processor Mods
		Telemetry Recorder/Server Mods
		Downlink TTM Controller Mods
Opto-mechanical System	Pickoff Exchange Mechanism	AO Bench Extension
		AO Bench Modified Cover
		Pickoff Stage Mount
		Pickoff Stage
		Pickoff Stage Motor, Encoder & Cable
		Pickoff Mount
		K'-Band Dichroic
		H-Band Dichroic
		Annular Mirror (option)

		Riser for Focus Stage
		Focus Stage
		Focus Stage Motor, Encoder & Cable
	Focus Mechanism	Mounting Plate to Camera Interface Plate
	AO Modifications	Modifications to Support Camera System
Controls System	OBS Modifications	Pickoff Stage Motion Control Hardware
		Pickoff Stage Motion Control Software
		Camera System Hardware Implementation
		Camera System Control Software
	SC Modifications	Modifications to RTC Interface
		DAR Compensation Modifications
		Focus Compensation Modifications
		Non-Sidereal Tracking Modifications (goal)
		Rotator Control Modifications (long term)
	RTC Modifications	Wavefront Controller Command Processor Mods
Operations Software System	Pre-Observing Tools	Acquisition Planning Tool Software
		Acquisition Planning Documentation
		Performance Estimation Tool Software
		Performance Estimation Documentation
	Observation Setup Software	OBS Setup Software
		SC Setup Software
		Camera System Setup Software
		RTC Setup Software
	Calibration Software	Camera Calibration Software
		Focus Calibration Software
		Distortion Mapping Software
	User Interfaces	Engineering GUI Additions/Modifications
		Observing UI Additions/Modifications
	Observing Tools & Sequences	Acquisition Software
		MAGIQ Software Modifications
		Nodding Script Modifications
		Dithering Script Modifications
		Repositioning Script Modifications
		Background Measurement Script Mods
		FITS Header Modifications
		Telemetry Data Recording Modifications
		TT Control Loop Parameter Optimization

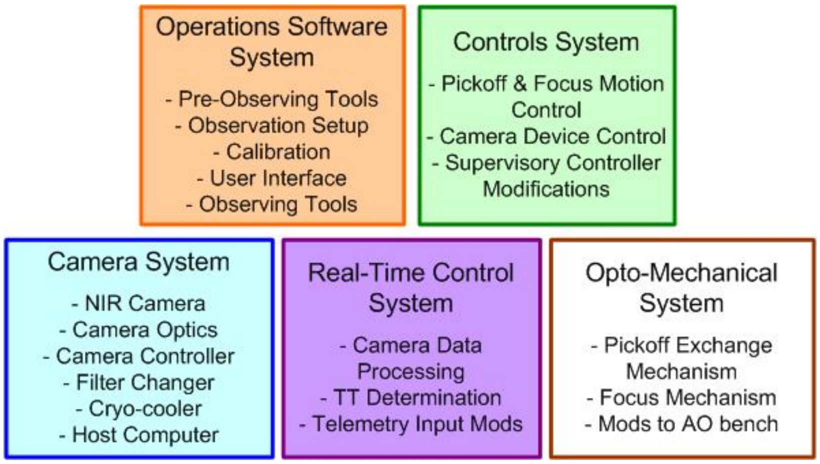


Figure 2: Block diagram summary of major NIR TTS subsystems and their key components

4. Project Plan and Schedule

4.1 Work Breakdown Structure

The top-level work breakdown structure is shown in Figure 3. WBS 1.3 to 1.7 correspond to the level 1 items in the PBS; i.e., the five NIR TTS subsystems shown in Figure 2. WBS 1.1, 1.2, 1.8 and 1.9 are system-wide activities.

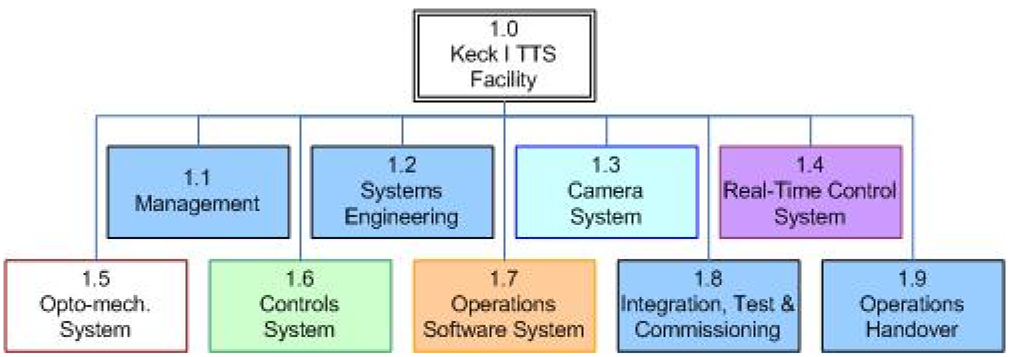


Figure 3: Top-level work breakdown structure

4.2 Milestones

Table shows the milestone dates in the original proposal and the plan presented in this SEMP. The handover review essentially marks the end of the project, except for some modest additional performance characterization and science verification that could run through an additional ~ 2 months.

The PDR is being held 3 months later than planned in the proposal, and 1 month late with respect to the PDR date proposed at the SDR (about 2 weeks of this delay are due to reviewer availability). The DDR date is a 2.5 month slip versus the proposal.

The TAC-allocation milestones indicate when both shared-risk and regular science with the NIR TTS should begin; the readiness for these milestones will be reviewed by the indicated dates. Overall the new schedule represents a 1 semester slip in the start of regular TAC-allocated science.

A rolled up version of the project plans, as submitted in the NSF ATI proposal, showing key milestones and work estimates is provided in section 9.

Table 3: Project Milestones

Milestone	Date in Proposal	Date in Current Plan
Project Start	8/1/10	8/1/10
System Design Review	11/8/10	12/7/10
Preliminary Design Review	1/31/11	4/25/11
Detailed Design Review	7/11/11	8/30/11
RTC Pre-Ship Review		1/30/12
Camera Pre-Ship Review	7/9/12	9/28/12
Pre-Summit Review	11/9/12	1/30/13
Handover Review	7/3/13	12/15/13
TAC-Allocation Milestones		
Readiness for 13B Shared-Risk		2/1/13
Start of TAC-allocated Shared-Risk		10/1/13
Readiness for 14A Science		8/1/13
Start of TAC-allocated Science	8/1/13	2/1/14

4.3 MS Project Plans

A total of four project plans have been prepared for the remainder of the project. Figure 4 is the project plan for the camera prepared by Caltech covering the detailed design through the completion of the project. Figure 5, Figure 6 and Figure 7 are the WMKO plans for the remaining three phases of the project, namely detailed design, full scale development, and delivery and commissioning, respectively. The project plans shown in this section are rolled up to high level tasks, the versions showing all subtasks can be found in section 0.

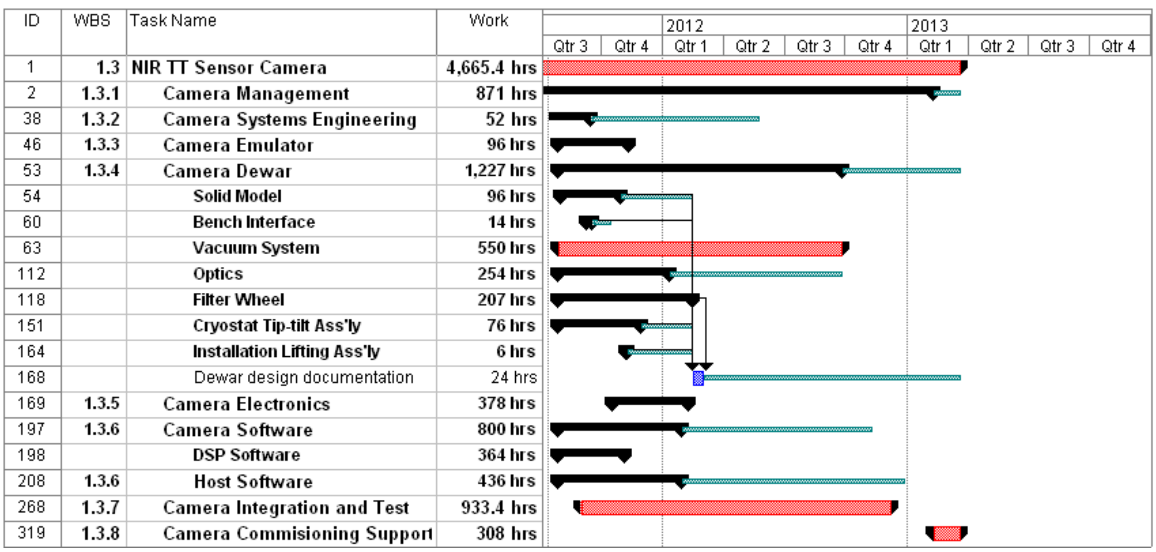


Figure 4: Caltech plan from start of detailed design through delivery

ID	WBS	Task Name	Work
1	**1**	**NIR TTS Detailed Design**	**1,525 hrs**
2	**1.1**	**Project Management**	**355 hrs**
11	**1.2**	**Systems Engineering**	**160 hrs**
23	1.3	Camera System	0 hrs
24	**1.4**	**Real-Time Control System Design**	**22 hrs**
27	**1.5**	**Opto-mechanical System**	**428 hrs**
28	**1.5.1**	**Optical Design and Documentation**	**138 hrs**
36	**1.5.2**	**Mechanical Design & Documentation**	**290 hrs**
50	**1.6**	**Controls System**	**229 hrs**
59	**1.7**	**Operations Software System**	**241 hrs**
75	**1.8**	**Integration, Test & Commissioning**	**54 hrs**
77	**1.9**	**Operations Handover**	**36 hrs**

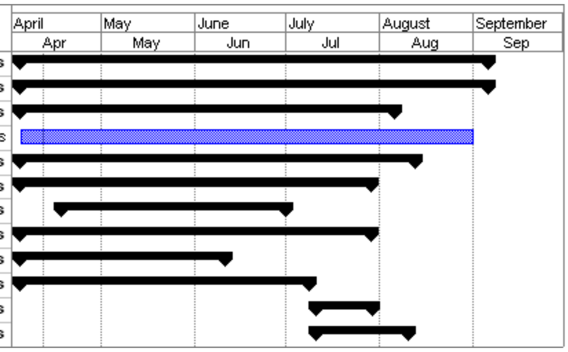


Figure 5: WMKO detailed design phase plan

ID	WBS	Task Name	Work
1	**1**	**Keck I TT Facility**	**2,483 hrs**
2	**1.1**	**Project Management**	**256 hrs**
12	**1.2**	**Systems Engineering**	**110 hrs**
23	**1.3**	**Camera System**	**120 hrs**
26	**1.4**	**Real-time Control**	**152 hrs**
31	**1.5**	**Opto-mechanics**	**326 hrs**
43	**1.6**	**Controls**	**510 hrs**
51	**1.7**	**Operations Software**	**933 hrs**
68	**1.8**	**Integration, Test & Commissioning**	**32 hrs**
70	**1.9**	**Operations Handover**	**44 hrs**

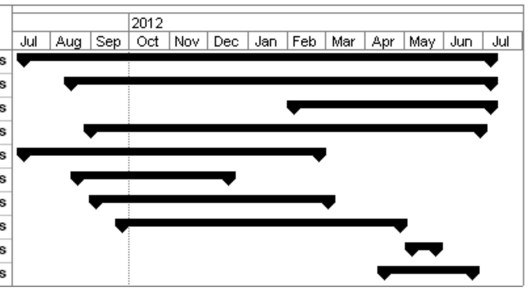


Figure 6: WMKO full scale development phase plan

ID	WBS	Task Name	Work
1	1	Keck I TT Facility	**2,242 hrs**
2	1.1	Project Management	**142 hrs**
3	1.1.1	Planning & Tracking	**32 hrs**
6	1.1.2	Meetings	**110 hrs**
9	1.1.3	Milestones & Design Reviews	**0 hrs**
10	1.1.3.1	Detailed Design Review	0 hrs
11	1.1.3.2	TTF Sensor Pre-Ship Review	0 hrs
12	1.1.3.3	Pre-Summit Review	0 hrs
13	1.1.3.4	Readiness for 13B Shared Risk Review	0 hrs
14	1.1.3.5	Handover Review	0 hrs
15	1.1.3.6	TAC-allocated Science Starts	0 hrs
16	1.2	Systems Engineering	**60 hrs**
21	1.3	HQ Preparation	**56 hrs**
24	1.4	Telescope Preparation	**240 hrs**
27	1.5	Telescope I&T	**1,416 hrs**
64	1.6	Commissioning and Handover	**248 hrs**
72	1.7	Science Verification	**80 hrs**

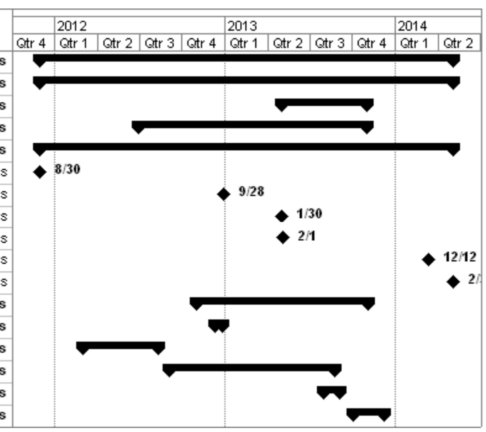


Figure 7: WMKO Delivery and Commissioning Plan

5. Budget

5.1 Revised Proposal Budget

The original proposal amount was $1966k. At NSF's request this budget was revised downward to $1716k; a total reduction of $250k. The WMKO Director agreed to a cost share of $15k in year 3 and $28k in year 4, and to cover the 483h of support astronomer time ($47k with indirect). The remainder was achieved with a $62k reduction in WMKO labor (an 8.5% reduction) and a $98k reduction in COO labor (a 12.5% reduction). These reductions essentially used the total contingency in the original proposal (10% at WMKO and ~$100k at COO).

The lack of contingency was identified as a critical issue at the SDR. In response, Hilton Lewis identified additional WMKO resources that could be applied to the project. These additional resources include $140k of flexible dollars and $100k of Keck labor in FY13.

In summary the resources for this project include:

- $1716k from NSF ATI
- $15k in FY11, $28k in FY12 and $240k in FY13 from WMKO
- 483h of support astronomer (SA) time from WMKO

5.2 Remaining Budget at PDR

The remaining budget is summarized as follows:

- $1716k - $325k - $329k = $1062k from NSF ATI
  - The spent dollars include $280k of planned procurements
- $15k in FY11, $28k in FY12 and $240k in FY13 from WMKO
- 483h – 8h – 61h = 414h of support astronomer time from WMKO

The subtractions above are from the SDR and PDR actuals discussed in sections 5.3.1 and 5.3.2, respectively. We have spent 33% of the NSF plus WMKO budget (22% of the budget excluding the $280k of procurements), and 14% of the SA hours. We have $1345k remaining.

5.3 Budget Actuals

5.3.1 Actuals through SDR

The total budget spent through SDR was $324,858 including $41,727 for labor, $256,000 for equipment, $375 for materials and $26,756 for indirect costs.

Only WMKO charged to this account in FY10 since a purchase order was not yet in place at Caltech. Caltech personnel (18h of Dekany and 33h of Smith) charged to the NGAO technical risk reduction budget. The FY10 actuals included 153 hours of labor (57h James, 1h Johansson, 14h LaVen, 12h Stalcup, 10h Wetherell and 60h Wizinowich). The total FY10 labor dollars was $11,916 or 78% of the budgeted $15,298 for WMKO labor. In addition there was $100 for supplies, $231 for phone calls and $6,865 for indirect costs.

The FY11 actuals through November 2010 included 388 hours of WMKO labor (97h James, 23h Neyman, 17h LaVen, 95h Stalcup, 2h Tsubota, 5h Wetherell, 141h Wizinowich and 8h of SA). The total labor dollars through November were $29,576 or 16% of the total dollars budgeted for WMKO labor in FY11. In addition there was $250,000 to Teledyne for the H2RG detector and $19,891 for indirect costs. In October and November Caltech personnel worked 25.5 hours on this project (38h Dekany and 45h Smith), again charged to the NGAO technical risk reduction budget. The December Caltech labor (25h Dekany, 19h Hale and 47h Smith) most of which was for the SDR was also charged to the NGAO technical risk reduction budget.

One additional procurement was placed and the parts were received: $6000 to ARC for a dual transmit ARC-22 timing board and an ARC-64 PCI interface board. The ARC procurement represents a $500 cost increase since the timing board had to be modified for dual channel output.

5.3.2 PDR Actuals versus Plan

The overall PDR actuals estimate is $329k including $124k of WMKO labor, $112k of Caltech labor, $24k of equipment, $1k of materials and $67k of indirect costs.

Although the PDR did not start until after the SDR on Dec. 7 the actuals listed here include all labor in December through February for WMKO and through March for Caltech. An estimate has been made for the remaining PDR labor through April 10 since these numbers are not yet available.

The PDR plan presented at SDR included 1227h of WMKO labor and 786h of Caltech labor.

The PDR actuals estimate is for 1573h of WMKO labor for a 28% increase (346h) over the plan. This corresponds to a $48k increase including indirect. The differences by individual can be seen in Table 4. The two large discrepancies are for Neyman and Wizinowich. In Neyman's case the AO software tools took much longer than planned mostly due to the learning curve of not using or creating the current tools; he also needed to spend extra time supporting software folks on the interactions between the NIR TTS and the AO supervisory controller. In Wizinowich's case, he ended up taking on some new responsibilities including the requirements, interfaces (including keywords) and calibrations, and addressing the cryocooler selection safety issues; the mechanical design support task also grew considerably. The next largest discrepancy is a transfer of the mechanical design work from James to Hess. Note that we utilized 53h of SA during the PD.

Table 4: WMKO preliminary design phase labor hours versus the plan

Name	PD Actual	PD Plan	Actuals-Plan
Campbell	17	0	17
Chin	3	0	3
Cooper	28	109	-81
Hess	110	0	110
James	37	136	-99
Johansson	0	0	0
Kinoshita	1	0	1
Kwok	6	10	-4
LaVen	268	287	-19
Lyke	44	79	-35
Neyman	472	215	257
Pollard	16	0	16
Randolph	9	0	9
Stalcup	115	107	8
Stomski	42	32	10
Tsubota	10	0	10
Tyau	36	34	2
Wetherell	5	0	5
Wizinowich	354	218	136
Total =	1573	1227	346

The PDR actuals estimate is for 1227h of Caltech labor for a 56% increase (441h) over the plan. The additional hours correspond to a $33k cost increase (this includes a higher rate for mechanical engineering than in the SDR plan). The differences by individual can be seen in Table 5. The largest discrepancy is for Hale. Originally unplanned work for Hale including validating the video link communications, evaluating the self heating effects and work on developing the camera emulator to be sent to Microgate. Smith ended up needing to spend unplanned time on the cryocooler selection (because of Keck safety issues) and ITAR issues imposed by the Teledyne detector and the Federal requirements flowdown in the subcontract from WMKO.

Table 5: Caltech preliminary design phase labor hours versus the plan

Name	PD Actual	PD Plan	Actuals-Plan
Bartos	327	252	75
Cromer	61	60	1
Dekany	34	84	-50
Hale	453	186	267
Rahmer	107	40	67
Smith	245	164	81
Total =	1227	786	441

The equipment cost includes $17k to Microgate to cover the system and preliminary design phases.

A procurement was placed in March for additional ARC components to allow for an interface emulator for Microgate in addition to the development system at Caltech: $7000 including an ARC-22 timing board (with dual channel output), a controller housing and power supply. The second timing board represents a $3000 cost increase since only one timing board was originally budgeted.

5.4 Budget Estimate at PDR

The overall project budget at PDR is presented in Table 6 by year. The total cost estimate (row J) is $1890k. After combining the $1716k of NSF funding (2nd last row of Table 6) with the $283k of WMKO funding (4th last row) the remaining contingency is $109k of WMKO funds (bottom right cell). Note that no indirect cost is charged to the WMKO funds.

Table 7 is the COO project budget which is listed as a subaward (row G.5) in the overall project budget.

The dollars by year for personnel are shown in sections A to C of Table 6 and Table 7. The equipment purchases over $5k are listed in section D of these two tables. Travel and other direct costs are shown in sections E and G, respectively. The indirect costs are calculated in section I.

The overall project cost estimate of $1890k, excluding contingency, is 4% less than the original proposal budget of $1966k. The cost increases and decreases with respect to the original proposal budget (not with respect to the budget presented at the SDR) are shown in Table 8.

Table 6: Overall project budget

Expenses		Person Months	Notes	Year One ACTUAL 8/1/10 9/30/10	Thru SDR 10/01/10 11/30/10	Year Two Thru PDR 12/01/10 4/10/11	4/11/11 9/30/11	Year Three 10/01/11 09/30/12	Year Four 10/01/12 09/30/13	Total Revised Budget
A. Senior Personnel	**Title**									
P. Wizinowich	Principal Investigat	2.4		$ 4,239	$ 9,930	$ 24,490	$ 17,170	$ 19,311	$ 6,866	$ 82,006
T. Stalcup	Project Manager	15		$ 670	$ 5,359	$ 6,200	$ 6,081	$ -		$ 18,311
(2) Total Senior Personnel		18	1	**$ 4,909**	**$ 15,289**	**$ 30,690**	**$ 23,251**	**$ 19,311**	**$ 6,866**	**$ 100,316**
B. Other Personnel										
(0) Post Doctoral Associates				$ -			$ -	$ -	$ -	$ -
(9) Other Professionals		23	1	$ 4,922	$ 8,221	$ 59,844	$ 49,304	$ 129,349	$ 110,699	$ 362,340
(0) Graduate Students				$ -			$ -			$ -
(0) Undergraduate Students				$ -			$ -			$ -
(1) Secretarial - Clerical (If Charged Directly)			1	$ -	$ -	$ 1,202	$ 1,202	$ 546	$ -	$ 2,950
(0) Other				$ -						$ -
Total Salaries and Wages				**$ 9,831**	**$ 23,510**	**$ 91,736**	**$ 73,758**	**$ 149,206**	**$ 117,565**	**$ 465,606**
C. Fringe Benefits			2	$ 2,320	$ 6,066	$ 23,668	$ 19,029	$ 38,048	$ 29,943	$ 119,073
Total Salaries, Wages and Fringe Benefits				**$ 12,151**	**$ 29,576**	**$ 115,404**	**$ 92,787**	**$ 187,254**	**$ 147,508**	**$ 584,679**
D. Equipment										
H2RG detector				$ -	$ 250,000				$ -	$ 250,000
ARC SDSU-III readout electronics				$ -	$ 6,000	$ 7,000		$ 8,500		$ 21,500
Microgate RTC modifications				$ -		$ 16,950	$ 10,170	$ 40,680		$ 67,800
Dewar optics				$ -			$ -	$ 21,500		$ 21,500
Dichroic beamsplitter				$ -			$ -	$ 10,000		$ 10,000
Pickoff optics stage				$ -			$ -	$ 7,000		$ 7,000
Focus stage				$ -			$ -	$ 9,200	$ -	$ 9,200
Total Equipment				**$ -**	**$ 256,000**	**$ 23,950**	**$ 10,170**	**$ 96,880**	**$ -**	**$ 387,000**
E. Travel										
Domestic			3	$ -		$ 315	$ -	$ 4,400	$ -	$ 4,715
Foreign				$ -			$ -	$ -	$ -	$ -
F. Other Supplies				$ -			$ -	$ -	$ -	$ -
G. Other Direct Costs										
1. Materials and Supplies				$ 331	$ 44	$ 852	$ 1,000	$ 21,845	$ 500	$ 24,572
2. Publication Costs/Documentation/Dissemination				$ -			$ -	$ -	$ -	$ -
3. Consultant Services				$ -		$ 8,840	$ 20,800	$ -	$ -	$ 29,640
4. Computer Services				$ -	$ -	$ 38	$ -	$ -	$ -	$ 38
5. Subawards	CIT		4	$ -	$ -	$ 112,105	$ 109,755	$ 340,781	$ -	$ 562,640
6. Other				$ -			$ -	$ -	$ -	$ -
Total Other Direct Costs				**$ 331**	**$ 44**	**$ 121,835**	**$ 131,555**	**$ 362,626**	**$ 500**	**$ 616,890**
H. Total Direct Costs				**$ 12,482**	**$ 285,620**	**$ 261,503**	**$ 234,512**	**$ 651,159**	**$ 148,008**	**$ 1,593,285**
I. Indirect Costs (F&A)										
Modified total direct costs (Base)			5	$ 12,482	$ 29,620	$ 150,449	$ 114,587	$ 70,319	$ 117,143	$ 494,599
Rate		60.00%		$ 6,865	$ 19,891	$ 67,431	$ 90,096	$ 42,191	$ 70,286	$ 296,759
Total Indirect Costs				**$ 6,865**	**$ 19,891**	**$ 67,431**	**$ 90,096**	**$ 42,191**	**$ 70,286**	**$ 296,759**
J. Total Direct and Indirect Costs				**$ 19,347**	**$ 305,511**	**$ 328,934**	**$ 324,607**	**$ 693,351**	**$ 218,294**	**$ 1,890,044**
WMKO cost share available							$ 15,000	$ 28,000	$ 240,000	$ 283,000
WMKO cost share applied								$ 143,180	$ 30,865	$ 174,045
Revised Proposal Funding Profile				$ 314,511			$ 715,613	$ 498,447	$ 187,429	$ 1,716,000
Budget (Proposal + WMKO) - Plan				$ 295,164			$ 51,724	$ 0	$ 1	**$ 108,956**

Notes
1. Salaries are based on WMKO fiscal year 2011 rates with 2.0% inflation added in each subsequent year.
2. Fringe benefits are based on WMKO fiscal year 2011 rate of 25.8%.
3. 3 trips - 1 week each
4. Caltech subaward
5. MTDC base calculated from total direct costs minus Total Equipment and minus Subawards (except for the first $25k of the CIT subaward).

Table 7: Detailed CIT Project Budget (incorporated on line G.5 of Table 6)

Expenses		Person Months	Notes	Year One ACTUAL 8/1/10 9/30/10	Year Two Thru PDR 10/01/10 4/10/11	Year Two 4/11/11 09/30/11	Year Three 10/01/11 09/30/12	Year Four 10/01/12 09/30/13	Total
A. Senior Personnel	**Title**								
R. Dekany	Systems Engineer	2		$ -	$ 3,837	$ 3,168	$ 6,560	$ -	$ 13,564
R. Smith	NIR TTS Camera Lead	8		$ -	$ 20,498	$ 14,948	$ 30,956	$ -	$ 66,402
(2) Total Senior Personnel		11	1	**$ -**	**$ 24,335**	**$ 18,116**	**$ 37,516**	**$ -**	**$ 79,967**
B. Other Personnel									
(0) Post Doctoral Associates				$ -		$ -	$ -	$ -	$ -
(4) Other Professionals		30	1	$ -	$ 63,868	$ 69,338	$ 148,684	$ -	$ 281,891
(0) Graduate Students				$ -		$ -			$ -
(0) Undergraduate Students				$ -		$ -			$ -
(0) Secretarial - Clerical (If Charged Directly)			1	$ -		$ -	$ -	$ -	$ -
(0) Other				$ -					$ -
Total Salaries and Wages				**$ -**	**$ 88,203**	**$ 87,454**	**$ 186,201**	**$ -**	**$ 361,857**
C. Fringe Benefits			2	$ -	$ 22,492	$ 22,301	$ 47,481	$ -	$ 92,274
Total Salaries, Wages and Fringe Benefits				**$ -**	**$ 110,694**	**$ 109,755**	**$ 233,682**	**$ -**	**$ 454,131**
D. Equipment									
Cryocooler						$ -	$ 16,445		$ 16,445
Lakeshore Controller							$ 8,049		$ 8,049
Host Computer							$ 5,500		$ 5,500
Total Equipment				**$ -**		**$ -**	**$ 29,994**	**$ -**	**$ 29,994**
E. Travel									
Domestic			3	$ -	$ 393	$ -	$ 4,400		$ 4,793
Foreign				$ -		$ -	$ -	$ -	$ -
F. Other Supplies				$ -		$ -	$ -	$ -	$ -
G. Other Direct Costs									
1. Materials and Supplies				$ -	$ 1,018	$ -	$ 33,310	$ -	$ 34,328
2. Publication Costs/Documentation/Dissemination				$ -		$ -	$ -	$ -	$ -
3. Consultant Services				$ -		$ -	$ -	$ -	$ -
4. Computer Services				$ -		$ -	$ -	$ -	$ -
5. Subawards				$ -		$ -	$ -	$ -	$ -
6. Other - shop fees for Fabrication				$ -		$ -	$ 39,395	$ -	$ 39,395
Total Other Direct Costs				**$ -**	**$ 1,018**	**$ -**	**$ 72,705**	**$ -**	**$ 73,723**
H. Total Direct Costs				**$ -**	**$ 112,105**	**$ 109,755**	**$ 340,781**	**$ -**	**$ 562,640**
I. Indirect Costs (F&A)									
Modified total direct costs (Base)						$ -	$ -	$ -	$ -
Rate		62.00%		$ -		$ -	$ -	$ -	$ -
Total Indirect Costs				**$ -**		**$ -**	**$ -**	**$ -**	**$ -**
J. Total Direct and Indirect Costs				**$ -**	**$ 112,105**	**$ 109,755**	**$ 340,781**	**$ -**	**$ 562,640**

Notes
1. Salaries are based on COO fiscal year 2011 rates, increased 3% annually.
2. Fringe benefits are based on COO fiscal year 2010 rate of 25.5%.
3. 2 trips - 1 week each
4. All Caltech items are part of an approved fabrication and carry no institutional overhead

Table 8: Comparison of budget at PDR to budget in original proposal

Category	Proposal	PDR Plan	Increase
WMKO Labor	$549,644	$614,319	$64,675
Caltech Labor	$581,905	$454,131	-$127,774
Camera Procurements	$371,960	$396,717	$24,757
Microgate Contract	$23,100	$67,800	$44,700
Other Procurements	$58,850	$50,810	-$8,078
Travel	$13,920	$9,508	-$4,412
Indirect	$366,536	$296,760	-$69,776
Total	$1,965,915	$1,890,044	-$75,871

5.5 Labor Estimate at PDR

The required WMKO personnel to complete the NIR TTS project are listed in Table 9. Overall the SD phase used 541h of WMKO labor (section 5.3.1) and the PD phase used 1573h (Table 4). Table 9 shows that another 6250h are required for an overall total of 8364h. This represents a 16% increase over the 7210h in the original proposal (Figure 13).

Table 9: WMKO Staffing by Phase

Name	FY11 DD	FY12 FSD	FY13 DC	Total
Campbell		8		8
Chin				0
Cooper	137	16	126	279
Hess	260			260
Honey		40	10	50
James		144	204	348
Kwok		40		40
LaVen	287	616	360	1263
Lyke	60	43	328	431
Martin		4	305	309
Mogenson		90		90
Morrison		0	64	64
Neyman	337	962	491	1790
Pollard	66	28	20	114
Stalcup	102			102
Tsubota		12		12
Tyau	36	16		52
Wizinowich	240	264	92	596
Wetherell		128		128
AO Software Eng			32	32
Mechanical Tech		56	184	240
Electronics Tech		16	26	42
Total	1525	2483	2242	6250

The WMKO FY11 plan has the personnel hours shown in Table 10 assigned to this project. The actuals through PDR and the remaining required hours to complete the detailed design phase (from Table 9) are also listed. The last column shows the difference between the FY11 plan and the revised expected actuals (negative means that more hours were required than planned).

Table 10: Remaining FY11 WMKO hours versus Observatory plan

Category	Name	FY11 Plan (hours)	Actuals (thru PDR)	Required hours	Plan – Actuals – Required
Support Astronomer	Campbell	83	21	0	62
	Conrad	77	0	0	77
	Lyke	0	48	60	-108
Mechanical	Hess	0	110	260	-370
	James	572	134	0	438
	Pollard	62	16	66	-20
	Randolph	0	9	0	-9
Electronics	Cooper	0	28	137	-165
	Wetherell	232	9	0	223
Software	Honey	40	0	0	40
	Kwok	0	6	0	-6
	LaVen	667	285	287	95
	Stomski	0	42	0	-42
	Tsubota	100	12	0	88
Optical Systems	Chin	0	3	0	-3
	Neyman	0	495	337	-832
	Stalcup	873	210	102	561
	Tyau	0	36	36	-72
	Wizinowich	83	495	240	-652
Total		2789	1959	1525	-695

All engineering disciplines except for optical systems are roughly equal between the plan and the actuals. Neyman and Wizinowich are now planned to spend 940h more in FY11 than originally planned from Stalcup and Wizinowich.

The required Caltech personnel to complete the NIR TTS project are listed in Table 11. Overall the SD phase used 225h of Caltech labor (section 5.3.1) and the PD phase used 1227h (Table 5). Table 11 shows that another 4585h are required for an overall total of 6037h. This represents a 21% decrease over the 7296h in the original proposal (after subtracting 276h of Stalcup from Figure 13).

Table 11: Caltech staffing by year

Name	FY11 ~DD	FY12 ~FSD	FY13 DC	Total
Richard Dekany	52	24	8	84
Roger Smith	244	254	41	539
Gustavo Rahmer	124	359	64	547
David Hale	661	231	81	973
John Cromer	375	195	141	711
Ernest Cromer	174	102		276
Viswa Velur	6	96		102
Jason Fucik	27	53		80
mechanical fab	505	5		510
Randy Bartos	460	108	85	653
Khanh Bui	110			110
Total	2738	1427	420	4585

5.6 Procurement Estimate at PDR

The procurement budget in the original proposal included $373,700 for equipment and $80,210k for materials, supplies and shop fees. The current budget (Table 6 and Table 7) includes $416,994 for equipment and $98,333 for materials, supplies and shop fees. Overall the procurements have grown by 14% from $453,910 to $515,327.

To date $330,800 of the procurement orders have already been placed, including the $67,800 fixed price contract to Microgate. Detailed procurement spreadsheets were prepared by Caltech and WMKO. Approximately $64k of the remaining $184k is from catalog prices or quotes.

5.7 Contingency at PDR

The remaining cost estimate for the detailed design phase through completion is $1236k. What part of this budget needs contingency? We assume that contingency is not needed on the remaining indirect costs ($203k) since the indirect cost recovery will be limited by the remaining NSF ATI funds. We only need to maintain a modest contingency, ~5%, on fixed price contracts ($51k remaining) and catalog prices or quotes ($64k remaining). At minimum we should have a 10% contingency on the rest of the remaining cost estimate. The desired contingency would therefore be ≥ ($1236k - $203k - $51k - $64k) * 10% + ($51k + $64k) * 5% = $98k. A more reasonable contingency would be to increase the 10% contingency number to 20% which would require $189k of contingency overall. Currently we have $109k or 10.6% contingency on the remaining costs excluding indirect costs. WMKO management has agreed to look at whether an additional $100k of observatory contingency can be identified to increase contingency to 20%.

The $81k or 33% cost overrun on the preliminary design phase versus the plan presented at SDR (see section 5.3.2) warrants a significant contingency and/or much improved project management. Some time was used during the preliminary design to ramp up team members on this project and to bring them up to speed. Now that the team is ramped up efficiency should be higher. We also went past the originally planned PDR level in some areas. The plans and cost estimates also have improved fidelity over those in the original proposal (we only updated the preliminary design phase plan for the SDR).

In preparing the current cost estimate we excluded goals including the use of three stars for tip-tilt, the use of a star for focus and an interactive performance prediction tool. We have however kept the infrastructure to allow these to be implemented in the future. Our remaining descope options appear to be relatively limited.

6. Configuration Control

Documents are maintained as Keck Adaptive Optics Notes (KAONs) in the KeckShare database. Drawings will be maintained in the mechanical and electronics databases, which are also available through KeckShare.

Four documents, representing all of the requirements and interfaces, are under configuration control as of the PDR:

- KAON 824: Microgate Statement of Work
- KAON 835: System and Functional Requirements Spreadsheet
- KAON 836: Camera to AO Interface Control Document
- KAON 857: Keyword Interface Spreadsheet

Changes to these documents must be tracked and approved by the project manager.
Engineering change requests (ECRs) are used to protect the operational systems. The ECRs indicate which change control boards (CCBs) are affected. The primary CCB review will be the AO CCB but there will be minor items for the telescope and instrument CCBs to review. The following draft ECRs have already been submitted through the SEED database, and will have initial reviews prior to the DDR:

- EC91418 for the OBS motion control modifications and motion stages
- EC91425 for the camera and opto-mechanics
- EC91433 for the camera support electronics
- EC91432 for the cryocooler

Several software ECRs have been posted and will also be submitted for review through the MANTIS database, again making sure to note the affected CCBs:

- Optics Bench software modifications
- Supervisory Controller software modifications
- Wavefront Controller software modifications
- Top-level software modifications

7. Risk Assessment

The JPL risk evaluation matrix approach used for the Keck Interferometer and NGAO was selected to track the significant programmatic and technical risks. This matrix ranks each risk by the consequences and likelihood of the risk occurring. A scale of 1 to 5 is used with higher numbers representing higher risk.

Likelihood of Occurrence:

Level	Definition	
5	Very High	> 70%, almost certain
4	High	>50%, more likely than not
3	Moderate	>30%, significant likelihood
2	Low	> 1%, unlikely
1	Very Low	<1%, very unlikely

Consequence of Occurrence – Programmatic Risks

(JPL's usage of "launch" replaced with "schedule")

Level	Implementation Risk Definition
5	Overrun budget & contingency. Cannot deliver.
4	Consume all contingency, budget or schedule
3	Significant reduction in contingency or schedule slack
2	Small reduction in budget or schedule slack
1	Minimal reduction in budget or schedule slack

Consequence of Occurrence – Technical Risks
(JPL's usage of "mission return" replaced with "science return")**:**

Level	Performance Risk Definition
5	Project Failure
4	Significant reduction in science return
3	Moderate reduction in science return
2	Small reduction in science return
1	Minimal or no impact to science return

The JPL-format risk matrix is shown in Figure 8. In this risk matrix red represents high risks that require implementation of new processes or a change in the baseline plan, yellow represents medium risks that need to be aggressively managed including considering alternative approaches, and green represents relatively low risks that should at least be monitored.

Table 12 lists the significant technical and programmatic risks. Two risks (items 7 and 8) were added subsequent to the SDR. Actions taken during the preliminary design lowered the likelihood on four risks.

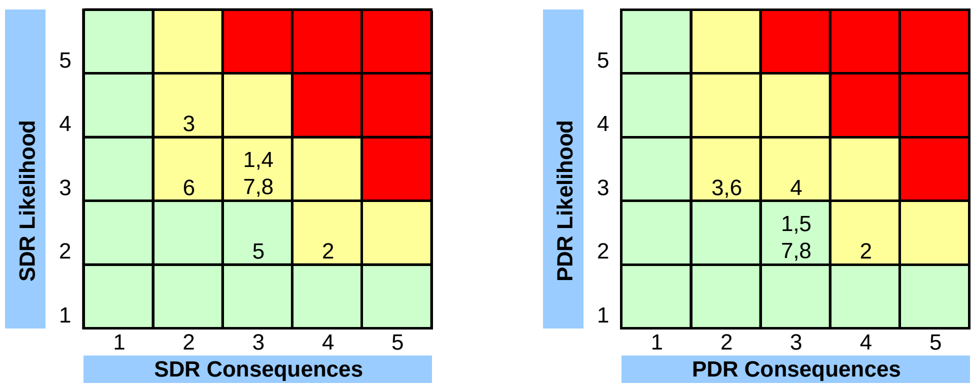


Figure 8: Programmatic and technical risk matrix

Table 12: Significant risk areas

#	Conse-quence	Like-lihood	Description	PDR	DD Proposed Mitigation
1	3	2	Tip-Tilt measurement accuracy requirement not achieved working off null	The selected approach (to allow the use of 3 stars, & to compensate for differential atmospheric refraction & to allow small positional adjustments) requires good tip-tilt performance even when the tip-tilt star is located up to 25 mas in x & y from the intersection of 4 pixels. The proposed correlation algorithm achieves the required performance. A tip-tilt mirror was incorporated in the PDR SolidWorks model but will not be initially implemented for cost reasons.	a) Will continue to implement both the correlation & centroiding approaches. b) Will ensure that the fold mirror can be replaced with a tip-tilt tracking mirror as part of the final SolidWorks model (as a future upgrade).

2	4	2	Advantages of NIR tip-tilt sensing not achieved	Many groups have predicted improvements with this technique but this is an unproven concept on the sky. Additional simulations were performed by van Dam during the PD which still show the advantage of NIR TT vs STRAP for a single star and limited off-axis distances; the performance is significantly improved when at least 2 NIR TT stars are used.	No work planned for DD.
3	2	3	Schedule delays due to personnel non-availability	The PDR is 1 month later than the date proposed at the SDR. Personnel availability continued to be a challenge in the early part of the PD. We do however largely have the staff currently to proceed at a good pace with the project. There is still a chance of being impacted by delays in the FST project & Stalcup's unavailability (which has been filled with Neyman & Wizinowich)	a) Wizinowich, Neyman & LaVen continuing in lead roles b) At WMKO project priority will increase as K1 free space transport & center launch system are completed in FY11. c) Collaborate with GMT for further analysis
4	3	3	Inadequate contingency (project requires more resources than budgeted)	Project already had effectively a \$160k reduction. Microgate fixed price quote assumes modification of an existing interface (desired interface protocol tested during PD). Subsequent to SDR WMKO committed an additional \$240k in FY12 & 13 to help with contingency. More detailed cost estimate prepared for PDR with better COO software estimates. PD costs higher than planned.	a) Perform a more careful cost evaluation for DDR. b) Only accept goals after sufficient budget clearly identified. c) Ensure DD phase stays in budget. d) Provide Microgate with camera emulator during DD.
5	3	2	Detector failure	We rely on 1 key & expensive (\$250k) component.	a) Smith has a spare detector that could be used as a backup
6	2	3	Conflicts with observing schedule impact delivery schedule	The observing schedule is defined in 6 month increments with some TBD engineering.	Not an issue to be addressed in DD phase. Longer term we will request adequate implementation gaps & engineering nights. A quick switch back to the operational system is practical.
7	3	2	Proposed camera data interface to RTC doesn't work	Interface proposed in Microgate SOW was untested at SDR. A modified camera timing board was procured & debugged during PD & the interface was successfully demonstrated on the camera side.	Will test on the Microgate side during DD

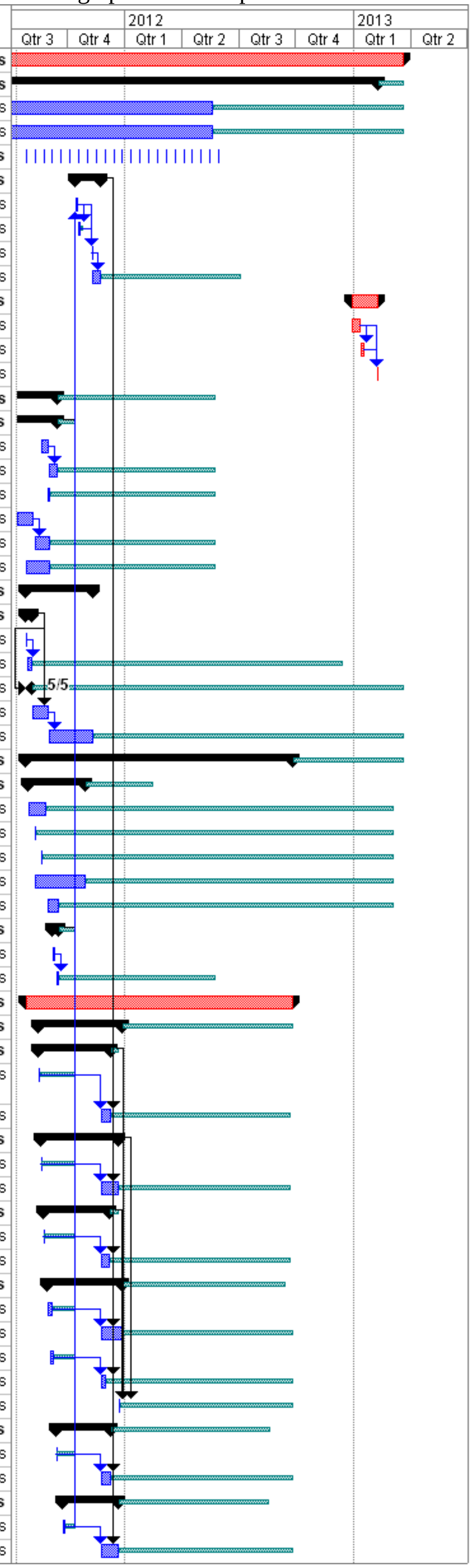
8	3	2	Self-heating of the detector doesn't allow for shifting regions of interest	Performed a self-heating test for shifting ROI during the PD. This does not impact the centroid.	Need to complete writing up the test results to be certain that the test was adequate.

8. Project Plan Details

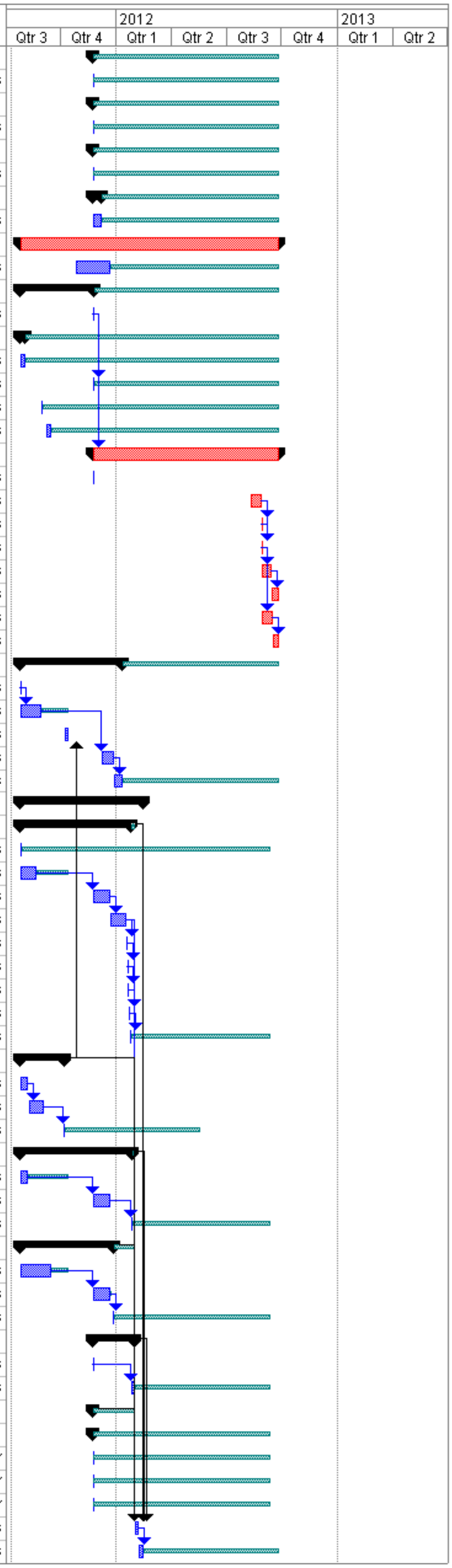
The project plans shown in section 4.3 have been expanded in the following figures.

Figure 9: Detailed Caltech plan for detailed design phase to completion

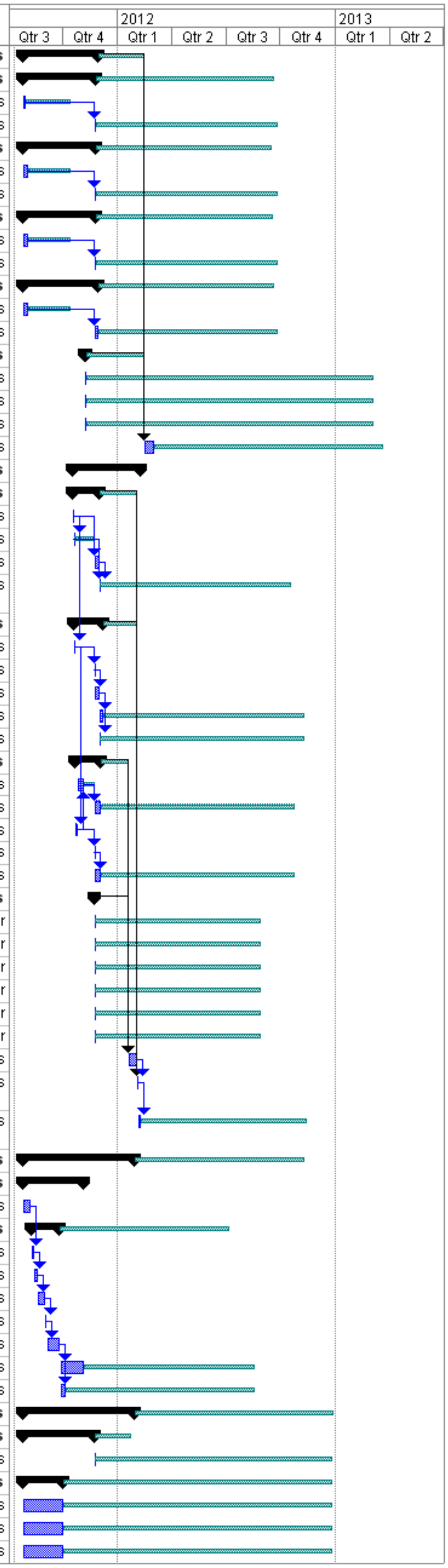
ID	WBS	Task Name	Work
1	1.3	**NIR TT Sensor Camera**	**4,665.4 hrs**
2	1.3.1	**Camera Management**	**871 hrs**
3		Camera Execution Management	60 hrs
4		Camera Technical Lead	300 hrs
5		**Internal Team Meetings**	**115 hrs**
29		**Detailed Design Review (DDR)**	**192 hrs**
30		Prepare DDR Documentation	64 hrs
31		Prepare DDR Presentation	64 hrs
32		Participate in DDR	32 hrs
33		Respond to DDR	32 hrs
34		**Preship Review (PSR)**	**204 hrs**
35		Prepare PSR Documentation	100 hrs
36		Prepare PSR Presentation	64 hrs
37		Participate in PSR	40 hrs
38	1.3.2	**Camera Systems Engineering**	**52 hrs**
39		**Interface Control Documents**	**52 hrs**
40		AO bench interface	8 hrs
41		Optical performance	8 hrs
42		AO Enclosure Seal Interface	8 hrs
43		Cooling system, compressor or He gas li	8 hrs
44		Electronics location, power, comms	8 hrs
45		Data and command flow	12 hrs
46	1.3.3	**Camera Emulator**	**96 hrs**
47		**Write DSP code**	**32 hrs**
48		Basic DSP commands to setup emulator	12 hrs
49		Implement a first-generation readout sch	20 hrs
50		Deliver Emulator to Microgate	0 hrs
51		Improve readout scheme	24 hrs
52		Software updates and support	40 hrs
53	1.3.4	**Camera Dewar**	**1,227 hrs**
54		**Solid Model**	**96 hrs**
55		Respond to PDR action items	40 hrs
56		Finalize interface to linear stage	4 hrs
57		Establish drawing numbers and drawing	4 hrs
58		Update solid models	24 hrs
59		Draft high-level ass'lys	24 hrs
60		**Bench Interface**	**14 hrs**
61		Finalize AO cover interface	6 hrs
62		Leach electronics mounting and interface	8 hrs
63		**Vacuum System**	**550 hrs**
64		**Vacuum Housing**	**200 hrs**
65		**Vacuum Housing Tube**	**32 hrs**
66		Generate vacuum housing tube and support structure shop	8 hrs
67		Fabricate housing tube and supp	24 hrs
68		**Top Plate**	**14 hrs**
69		Generated top plate shop drawin	6 hrs
70		Fabricate top plate	8 hrs
71		**Window Plate**	**6 hrs**
72		Produce window plate shop drav	2 hrs
73		Fabricate front flange and windov	4 hrs
74		**Internal Shields and Mounts**	**144 hrs**
75		Produce cold baffles shop drawi	16 hrs
76		Fabricate cold baffles	48 hrs
77		Produce radiation shields shop (	32 hrs
78		Fabricate radiation shields	48 hrs
79		Eppner Coat inside gold over nickel a	4 hrs
80		**Lens Tube**	**32 hrs**
81		Produce lens tube shop drawing	8 hrs
82		Fabricate lens tube	24 hrs
83		**Detector Mount**	**144 hrs**
84		Produce detector mount shop drawin	24 hrs
85		Fabricate detector mount and hatche	120 hrs



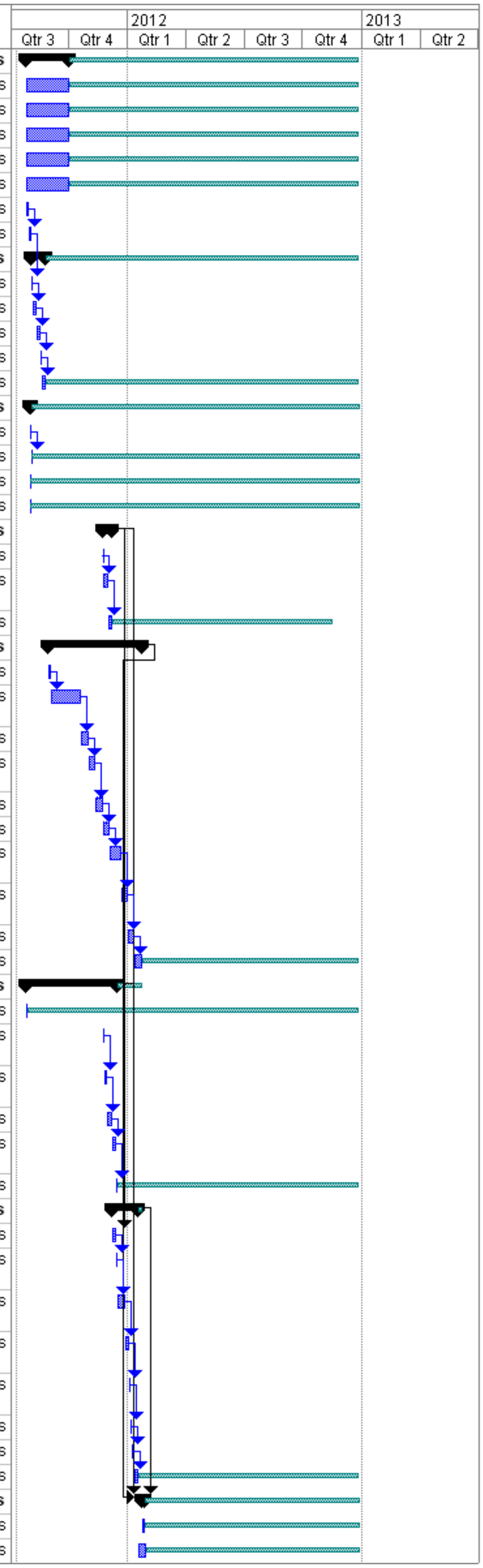
ID	WBS	Task Name	Work
86		**Ion Pump**	**2 hrs**
87		Procure ion pump	2 hrs
88		**Vacuum Valve**	**2 hrs**
89		Procure Vacuum Valve	2 hrs
90		**Relief Valve**	**2 hrs**
91		Procure Relief Valve	2 hrs
92		**Other Vacuum Fittings and Parts**	**8 hrs**
93		Procure other dewar parts: o-rings, ve	8 hrs
94		**Thermal Control System**	**160 hrs**
95		Refine thermal modelling & design	16 hrs
96		**Cryocooler**	**18 hrs**
97		Crycooler and lines purchase	4 hrs
98		**Compressor**	**8 hrs**
99		Design compressor mount a	8 hrs
100		Modification to Cold Head	6 hrs
101		Design and Fab Cold Plate	12 hrs
102		Thermal Strap Ass'ly	8 hrs
103		**Lakeshore 340 controller**	**106 hrs**
104		Purchase Lakeshore controller	2 hrs
105		Heater and sensors wiring desig	24 hrs
106		Purchase sensors	2 hrs
107		Thermal Fuse	2 hrs
108		Install and wire temperature sen	24 hrs
109		Test sensors, heaters and servo	16 hrs
110		Fabricate cable from dewar to ter	20 hrs
111		Test sensors, heaters and servo	16 hrs
112		**Optics**	**254 hrs**
113		Window thicnkness selection (FEA?)	6 hrs
114		Design optics mounts	40 hrs
115		Pupil mask design & procurement	8 hrs
116		Fabricate optics mounts	120 hrs
117		Install optics in mounts	80 hrs
118		**Filter Wheel**	**207 hrs**
119		**Filter Wheel Bearing and Shaft Ass'ly**	**59 hrs**
120		Determine proper bearing springs	3 hrs
121		Produce shop drawings	16 hrs
122		Fab	8 hrs
123		G10 Shaft Coupling	20 hrs
124		Ferrofluidic feedthrough	2 hrs
125		Harmonic Drive	2 hrs
126		Stainless Steel Bellows	2 hrs
127		Bearings	2 hrs
128		Ass'ly	4 hrs
129		**Filter Wheel Cover and Fixed Lens Moun**	**20 hrs**
130		Design	8 hrs
131		Fab	8 hrs
132		Ass'ly	4 hrs
133		**Filter Wheel Alignment Pin Ass'ly**	**20 hrs**
134		Design	8 hrs
135		Fab	8 hrs
136		Ass'ly	4 hrs
137		**Gear Box / Encoder / Motor Ass'ly**	**54 hrs**
138		Design	30 hrs
139		Fab	8 hrs
140		Ass'ly	16 hrs
141		**Drive Motor**	**10 hrs**
142		motor and controller procurement	2 hrs
143		Ass'ly	8 hrs
144		**Micro-e Encoder**	**4 hrs**
145		**encoder procurements**	**4 hrs**
146		Encoder head	1 hr
147		Glass disk	1 hr
148		Extension cable	1 hr
149		Assembly and fit check	20 hrs
150		Clean, bake and reassemble	20 hrs



ID	WBS	Task Name	Work
151		**Cryostat Tip-tilt Ass'ly**	**76 hrs**
152		**Mounting Tube**	**18 hrs**
153		Produce Shop Drawings	6 hrs
154		Fab	12 hrs
155		**Tip-tilt Base**	**16 hrs**
156		Produce Shop Drawings	8 hrs
157		Fab	8 hrs
158		**Field Lens Mount**	**20 hrs**
159		Produce Shop Drawings	8 hrs
160		Fab	12 hrs
161		**Fold Mirror Mount**	**22 hrs**
162		Produce Shop Drawings	8 hrs
163		Fab	14 hrs
164		**Installation Lifting Ass'ly**	**6 hrs**
165		Slings	2 hrs
166		Shackles	2 hrs
167		Lifting Eyes	2 hrs
168		Dewar design documentation	24 hrs
169	**1.3.5**	**Camera Electronics**	**378 hrs**
170		**Internal Dewar Wiring**	**42 hrs**
171		Design detector wiring within dewar	8 hrs
172		Procure hermetic connectors	2 hrs
173		Cable Assembly	24 hrs
174		Fabricate heater and temperature sensor wiring inside dewar and ohmic check	8 hrs
175		**External Wiring**	**102 hrs**
176		Design cables from dewar to controller	24 hrs
177		Procure circular connectors for cables to	2 hrs
178		Fabricate and check cables from dewar t	48 hrs
179		Fabricate cable form dewar to temp contr	20 hrs
180		Install cable from dewar to temp controlle	8 hrs
181		**Electronics Enclosure**	**144 hrs**
182		Mechanical design of ARC electronics en	40 hrs
183		Mechanical Fab	16 hrs
184		Design wiring within controller	24 hrs
185		Procure D connectors within controller	4 hrs
186		Fabricate and check wiring within controll	60 hrs
187		**32-channel IR ARC electronics**	**6 hrs**
188		6-slot housing (ARC-70)	1 hr
189		Large power supply (ARC-80)	1 hr
190		PCI card (ARC-64)	1 hr
191		Timing board (ARC-22)	1 hr
192		Universal Clock Driver (ARC-32)	1 hr
193		One 8-ch IR Video Board (ARC-46)	1 hr
194		Test ARC controller	60 hrs
195		End-to-end ohmic check from detector mount to controller	8 hrs
196		Oscilloscope check of signals in cable at dewar end	16 hrs
197	**1.3.6**	**Camera Software**	**800 hrs**
198		**DSP Software**	**364 hrs**
199		Define TRICK readout mode and new cor	80 hrs
200		**Write and test TRICK readout mode DSP**	**140 hrs**
201		SEX, PON, POF, SBN, SMX, SET, SV(	16 hrs
202		SSS, SSP, SWG, FSM	16 hrs
203		ROI, CPR	40 hrs
204		VON, VOF	8 hrs
205		Readout mode algorithm	60 hrs
206		Testing and debugging	120 hrs
207		Documentation for new commands	24 hrs
208	**1.3.6**	**Host Software**	**436 hrs**
209		**Host Computer**	**72 hrs**
210		Purchase Sun server, rack mount	4 hrs
211		**Platform Configuration**	**32 hrs**
212		Backups	4 hrs
213		OS patches and upgrades	4 hrs
214		Security	4 hrs



ID	WBS	Task Name	Work
215		**Component software installatio**	**20 hrs**
216		CVS	4 hrs
217		VNC	4 hrs
218		SSH	4 hrs
219		Tcl/Tk	4 hrs
220		JAVA	4 hrs
221		Set up and configure at CIT (account	8 hrs
222		Install and test ARC hardware and sc	8 hrs
223		**Configure for keck development (kr**	**20 hrs**
224		Show	4 hrs
225		Modify	4 hrs
226		Waitfor	4 hrs
227		Cshow	4 hrs
228		Xshow	4 hrs
229		**Networked power switch**	**10 hrs**
230		Purchase Remote power switch	2 hrs
231		Configure and test communications	4 hrs
232		Demonstrate switching outlets on/off	2 hrs
233		Write application note.	2 hrs
234		**Terminal Server**	**16 hrs**
235		Purchase Terminal server, rack mou	4 hrs
236		Set up and configure terminal server for network access	8 hrs
237		Test terminal server	4 hrs
238		**Detector Server**	**184 hrs**
239		Write design note	8 hrs
240		Initial port and customization of OSIRIS/NIRES/MOSFIRE code.	40 hrs
241		Add additional functionality.	16 hrs
242		Demonstrate required sampling/coadd modes.	16 hrs
243		Demonstrate correct FITS file produc	16 hrs
244		Demonstrate video on/off switches c	16 hrs
245		Demonstrate "filmstrip" FITS file produced correctly.	24 hrs
246		Demonstrate windowed dark and flat exposures done correctly.	16 hrs
247		Revise design note based on as-buil	16 hrs
248		Write application note.	16 hrs
249		**Temperature Server**	**34 hrs**
250		Write design note.	4 hrs
251		Configure and test communications (RS232, terminal server).	4 hrs
252		Initial port and customization of MOSFIRE code.	4 hrs
253		Demonstrate parameter control and	12 hrs
254		Demonstrate temp sensor values displayed and logged.	8 hrs
255		Revise design note based on as-buil	2 hrs
256		**Filter Server**	**56 hrs**
257		Write design note.	8 hrs
258		Configure and test communications (RS232 or Network).	4 hrs
259		Initial port of and customization of MOSFIRE code.	16 hrs
260		Demonstrate configuration of motion controller.	8 hrs
261		Demonstrate "homing", recovery from lost position.	4 hrs
262		Demonstrate set filter correctly.	4 hrs
263		Revise design note based on as-buil	4 hrs
264		Write application note.	8 hrs
265		**Global Server**	**24 hrs**
266		Support implementation by Alan Hon	24 hrs
267		Operators manual	40 hrs



ID	WBS	Task Name	Work
268	**1.3.7**	**Camera Integration and Test**	**933.4 hrs**
269		Assembly tooling	8 hrs
270		Lifting hardware proof test	3 hrs
271		**Vacuum and thermal tests**	**138.4 hrs**
272		Assemble vacuum housing & test with cr	48 hrs
273		Test relief valve	4 hrs
274		Check and fix leaks	12 hrs
275		Pump and bake dewar	2.4 hrs
276		Pressure rise tests	12 hrs
277		Log temperature through1st cooldown	16 hrs
278		Adjust thermal servo	8 hrs
279		Log temperature through1st warm up	8 hrs
280		Tune thermal links	16 hrs
281		Pump, repeat thermal cycle, servo tuning	12 hrs
282		**Filter Mechanism tests**	**28 hrs**
283		Test filter wheel mechanism warm, using encoder to test positioning	12 hrs
284		Demonstrate filter placement meets accuracy and precision requirements	16 hrs
285		**Detector tests**	**332 hrs**
286		**ELECTRA dewar tests**	**276 hrs**
287		Detector installation	16 hrs
288		**Verify Readout modes, image formatting and headers**	**8 hrs**
289		Test Full Frame (1-ch and 32-ch) and Window Mode	8 hrs
290		**H2RG Optimization**	**80 hrs**
291		Minimize Frame and Line Overhe	24 hrs
292		**Global Reset**	**56 hrs**
293		Investigate	8 hrs
294		Implement	8 hrs
295		Mitigate	40 hrs
296		**Characterize H2RG detector perforn**	**172 hrs**
297		Variance curve, conversion gain and full well	16 hrs
298		Dark current vs temperature	16 hrs
299		Cosmic rays rate check	4 hrs
300		Image persistence	8 hrs
301		**H2RG Noise Performance Testi**	**96 hrs**
302		Write Matlab code for noise performance data analysis	16 hrs
303		Measurements/data taking for H2RG noise	24 hrs
304		Noise performance analysis	40 hrs
305		Writeup noise performance r	16 hrs
306		Write test reports	32 hrs
307		**TRICK dewar integration**	**56 hrs**
308		Check signals at detector mount end	8 hrs
309		Detector installation	16 hrs
310		Initial operation of detector using host computer	16 hrs
311		Noise and dark current check	16 hrs
312		Communication test to AO controller simulato	32 hrs
313		Test reports (performance verification)	80 hrs
314		Maintenance procedures and diagnostics	80 hrs
315		**Optical tests**	**232 hrs**
316		Install and align optics warm	56 hrs
317		Align & test optics cold	56 hrs
318		Spot/pinhole centroiding tests in lab using projector	120 hrs
319	**1.3.8**	**Camera Commisioning Support**	**308 hrs**
320		Pack ship shipping of hardware, incl insuranc	48 hrs
321		On-site testing and debugging	160 hrs
322		Host layer programming support from Pasad	100 hrs

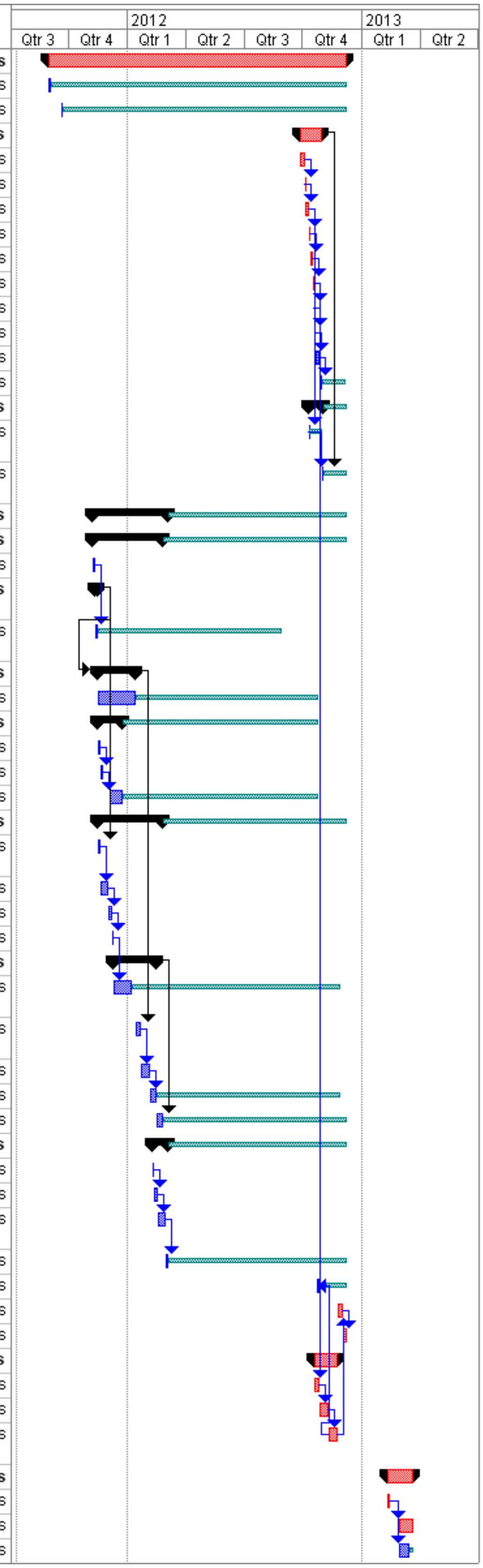
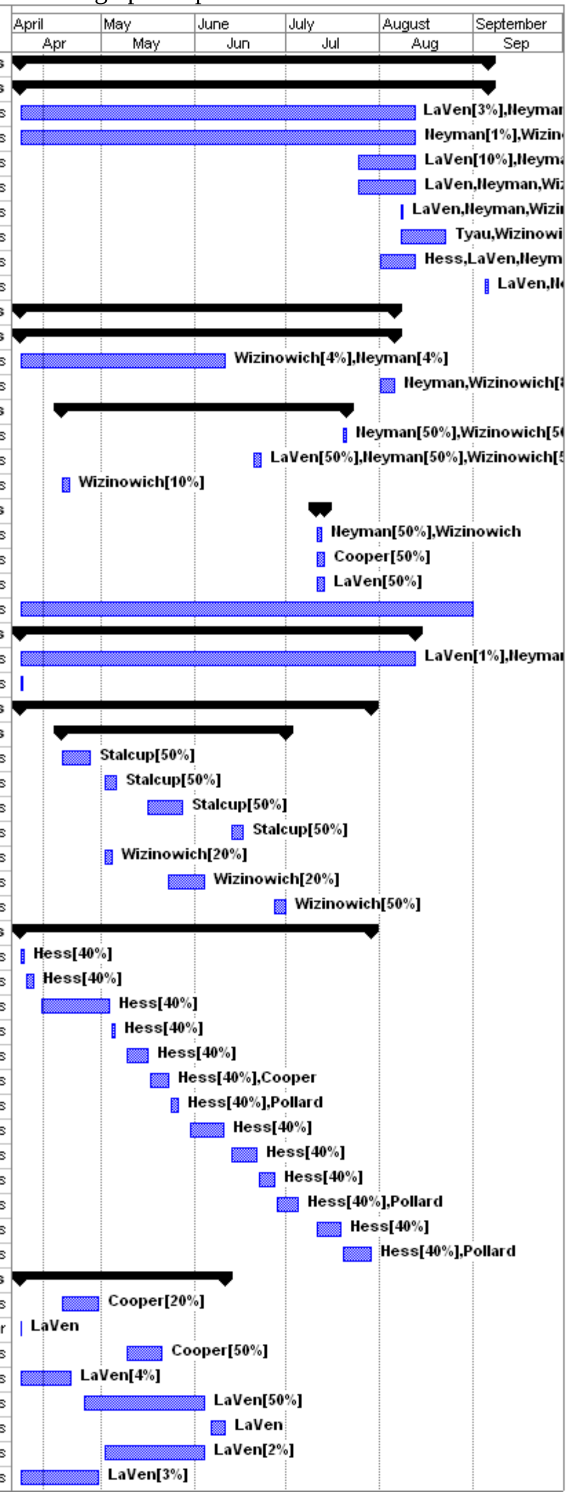


Figure 10: WMKO detailed design phase plan

ID	WBS	Task Name	Work
1	1	**NIR TTS Detailed Design**	**1,525 hrs**
2	**1.1**	**Project Management**	**355 hrs**
3	1.1.1	Engineering Meetings (~20)	110 hrs
4	1.1.2	Quarterly Science Meeting (~2)	8 hrs
5	1.1.3	Cost Estimate Update	52 hrs
6	1.1.4	Schedule Update	34 hrs
7	1.1.5	Risk Update	11 hrs
8	1.1.6	SEMP Update	48 hrs
9	1.1.7	DDR preparations	56 hrs
10	1.1.8	DDR	36 hrs
11	**1.2**	**Systems Engineering**	**160 hrs**
12	**1.2.1**	**System Architecture Design**	**88 hrs**
13	1.2.1.1	Performance & Budget Updates	20 hrs
14	1.2.1.2	Design Manual Update	68 hrs
15	**1.2.2**	**Requirements & Interfaces**	**32 hrs**
16	1.2.2.1	Requirements Spreadsheet Updates	8 hrs
17	1.2.2.2	Keyword Spreadsheet Updates	22 hrs
18	1.2.2.3	Camera to AO ICD Updates	2 hrs
19	**1.2.3**	**Engineering Change Control**	**40 hrs**
20	1.2.3.1	AO ECR	16 hrs
21	1.2.3.2	Electrical ECR	12 hrs
22	1.2.3.3	Software ECR	12 hrs
23	1.3	Camera System	0 hrs
24	**1.4**	**Real-Time Control System Design**	**22 hrs**
25	1.4.1	Microgate Contract Design Support	22 hrs
26	1.4.2	Microgate Contract	0 hrs
27	**1.5**	**Opto-mechanical System**	**428 hrs**
28	**1.5.1**	**Optical Design and Documentation**	**138 hrs**
29	1.5.1.1	Optical Design	30 hrs
30	1.5.1.2	Optics Thermal Analysis	16 hrs
31	1.5.1.3	Optics Tolerance Analysis	40 hrs
32	1.5.1.4	Optics Documentation for Fab/Quotes	16 hrs
33	1.5.1.5	Dichroic Documentation for Fab/Quotes	4 hrs
34	1.5.1.6	Alignment Plan Details	16 hrs
35	1.5.1.7	Optics Quotes	16 hrs
36	**1.5.2**	**Mechanical Design & Documentation**	**290 hrs**
37	1.5.2.1	Planning, Setup & Administration	6 hrs
38	1.5.2.2	Top Level System	8 hrs
39	1.5.2.3	Assembly Pickoff Optics	53 hrs
40	1.5.2.4	Assembly Focus Stage	6 hrs
41	1.5.2.5	Compressor System	18 hrs
42	1.5.2.6	Electronics	30 hrs
43	1.5.2.7	Installation	21 hrs
44	1.5.2.8	Dust Cover Extension	30 hrs
45	1.5.2.9	Other AO Modifications	22 hrs
46	.5.2.10	Configuration Control	12 hrs
47	.5.2.11	Documentation Review & Followup	32 hrs
48	.5.2.12	Contingency	20 hrs
49	.5.2.13	Mechanics Quotes	32 hrs
50	**1.6**	**Controls System**	**229 hrs**
51	1.6.1	OBS Motion Control Hardware	16 hrs
52	1.6.2	OBS Motion Control Software	1 hr
53	1.6.3	Camera Device Control Hardware	40 hrs
54	1.6.4	Camera Device Control Software	4 hrs
55	1.6.5	Centeroid Offset Calcs (DAR, et al)	120 hrs
56	1.6.6	Focus Compensation Mods	40 hrs
57	1.6.7	WCP Modifications	4 hrs
58	1.6.8	Telemetry Recorder Software	4 hrs



ID	WBS	Task Name	Work
59	**1.7**	**Operations Software System**	**241 hrs**
60	1.7.1	AO Guide Star Selection Tool	5 hrs
61	1.7.2	NIRTTS/ACAM display tool (New tool)	25 hrs
62	1.7.3	NIRTTS Planning Widget (New tool)	8 hrs
63	1.7.4	Performance Estimation Tool (IDL)	0 hrs
64	1.7.5	Setup Scripts (Mods)	10 hrs
65	1.7.6	Camera Calibrations (IDL)	15 hrs
66	1.7.7	Focusing Calibration (IDL)	10 hrs
67	1.7.8	NIR TTS status Tool (New Tool)	15 hrs
68	1.7.9	NIRTTS interaction matrix (IDL)	10 hrs
69	1.7.10	Distortion Mapping (IDL)	10 hrs
70	1.7.11	AO Acquisition and setup tool (IDL)	45 hrs
71	1.7.12	Repositioning Tool (New tool)	30 hrs
72	1.7.13	Background Measurement	30 hrs
73	1.7.14	Optimization & control loop tools	20 hrs
74	1.7.15	AO Alarm Handler	8 hrs
75	**1.8**	**Integration, Test & Commissioning**	**54 hrs**
76	1.8.1	Plan Details	54 hrs
77	**1.9**	**Operations Handover**	**36 hrs**
78	1.9.1	Draft Plan	36 hrs

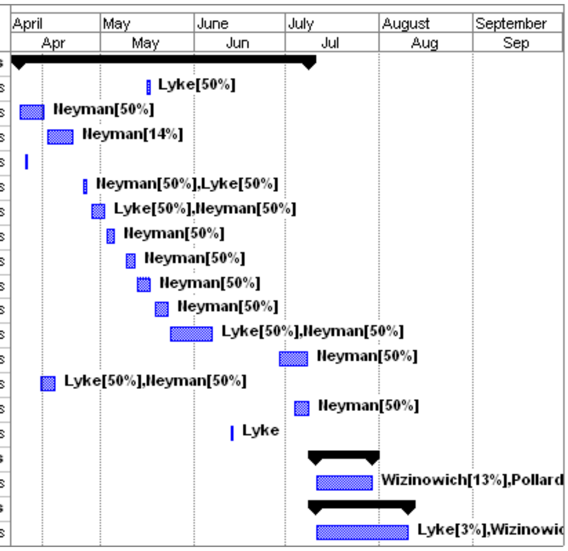
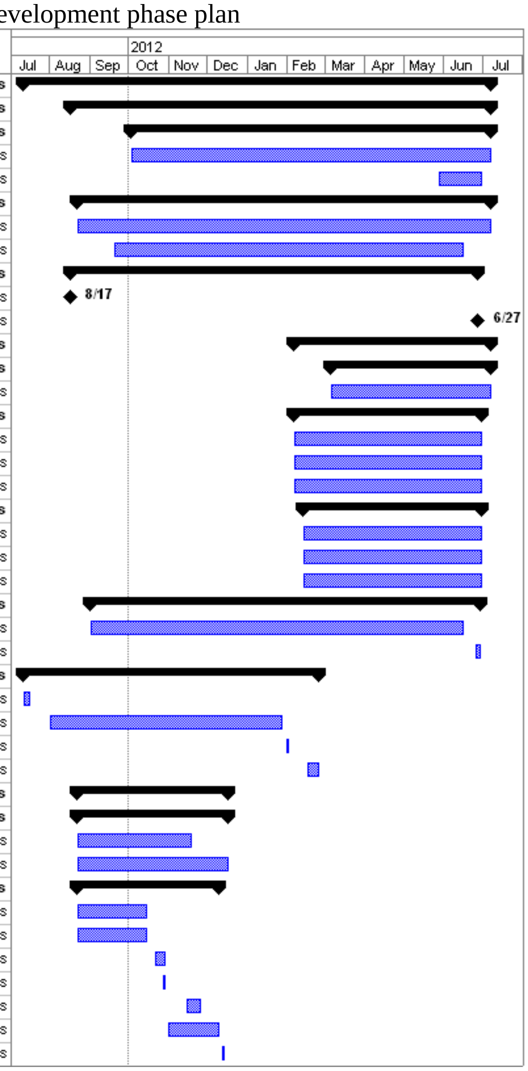


Figure 11: WMKO full scale development phase plan

ID	WBS	Task Name	Work
1	**1**	**Keck I TT Facility**	**2,483 hrs**
2	**1.1**	**Project Management**	**256 hrs**
3	**1.1.1**	**Planning & Tracking**	**64 hrs**
4	1.1.1.1	Cost Update	32 hrs
5	1.1.1.2	Schedule Update	32 hrs
6	**1.1.2**	**Management & Reporting**	**192 hrs**
7	1.1.2.1	Weekly Engineering Meetings	180 hrs
8	1.1.2.2	Quarterly Science Meetings	12 hrs
9	**1.1.3**	**Milestones & Design Reviews**	**0 hrs**
10	1.1.3.1	Detailed Design Review	0 hrs
11	1.1.3.2	Camera Pre-Ship Review	0 hrs
12	**1.2**	**Systems Engineering**	**110 hrs**
13	**1.2.1**	**System Architecture Design**	**40 hrs**
14	1.2.2	Design Manual Update	40 hrs
15	**1.2.2**	**Requirements and Interfaces**	**22 hrs**
16	1.2.3	Requirements Spreadsheet Updates	10 hrs
17	1.2.4	Keyword Spreadsheet Updates	8 hrs
18	1.2.2.3	Camera to AO ICD Updates	4 hrs
19	**1.2.5**	**Engineering Change Control**	**48 hrs**
20	1.2.3.1	AO ECR	16 hrs
21	1.2.3.2	Electrical ECRs	16 hrs
22	1.2.3.3	Software ECRs	16 hrs
23	**1.3**	**Camera System**	**120 hrs**
24	1.3.1	Support Caltech Development	24 hrs
25	1.3.2	Camera Pre-Ship Acceptance Review	96 hrs
26	**1.4**	**Real-time Control**	**152 hrs**
27	1.4.1	Ship Spare RTC Unit to Microgate	16 hrs
28	1.4.2	Support Microgate Development	32 hrs
29	1.4.3	RTC Pre-Ship Acceptance Review	32 hrs
30	1.4.4	Receive, Setup & Test Modified RTC Unit	72 hrs
31	**1.5**	**Opto-mechanics**	**326 hrs**
32	**1.5.1**	**Optics Fabrication**	**36 hrs**
33	1.5.1.1	Optics Procurement	20 hrs
34	1.5.1.2	Dichroic Procurement	16 hrs
35	**1.5.2**	**Mechanical Fabrication & Assembly**	**266 hrs**
36	1.5.2.1	Mechanical Procurement	24 hrs
37	1.5.2.2	Mechanical Fabrication Oversight	16 hrs
38	1.5.2.3	Pickoff Optics Assembly	40 hrs
39	1.5.2.4	Focus Stage Assembly	12 hrs
40	1.5.2.5	Other AO Modifications	74 hrs
41	1.5.2.6	As-Built Documentation	100 hrs
42	1.5.3	O-M Pre-Lab I&T Acceptance Review	24 hrs



ID	WBS	Task Name	Work
43	**1.6**	**Controls**	**510 hrs**
44	1.6.1	Motion Control	72 hrs
45	1.6.2	Camera Control	68 hrs
46	1.6.3	Centroid Offset Calculation	142 hrs
47	1.6.4	Focus Compensation Modifications	40 hrs
48	1.6.5	Wavefront Controller Command Processor Mods	80 hrs
49	1.6.6	Telemetry Recorder System Mods	76 hrs
50	1.6.7	Controls Pre-Lab I&T Acceptance Review	32 hrs
51	**1.7**	**Operations Software**	**933 hrs**
52	1.7.1	AO Guide Star Selection Tool	50 hrs
53	1.7.2	NIR TTS/ACAM Display Tool	100 hrs
54	1.7.3	NIR TTS Planning Widget	8 hrs
55	1.7.4	Performance Estimation Tool	8 hrs
56	1.7.5	Setup Scripts Modifications	60 hrs
57	1.7.6	Camera Calibrations IDL Tool	60 hrs
58	1.7.7	Focusing Calibration IDL Tool	60 hrs
59	1.7.8	NIR TTS Status Tool	100 hrs
60	1.7.9	NIR TTS Interaction Matrix IDL Tool	60 hrs
61	1.7.10	Distortion Mapping IDL Tool	40 hrs
62	1.7.11	AO Acquisition & Setup IDL Tool	140 hrs
63	1.7.12	Repositioning Tool	90 hrs
64	1.7.13	Background Measurement Tool	60 hrs
65	1.7.14	Optimization & Control Loop Tools	60 hrs
66	1.7.15	AO Alarm Handler	1 hr
67	1.7.16	Operations Software Pre-Lab I&T Acceptance Review	36 hrs
68	**1.8**	**Integration, Test & Commissioning**	**32 hrs**
69	1.8.1	I&T Plan Update	32 hrs
70	**1.9**	**Operations Handover**	**44 hrs**
71	1.9.1	Operations Documentation Update	36 hrs
72	1.9.2	Operations Training Plan Update	8 hrs

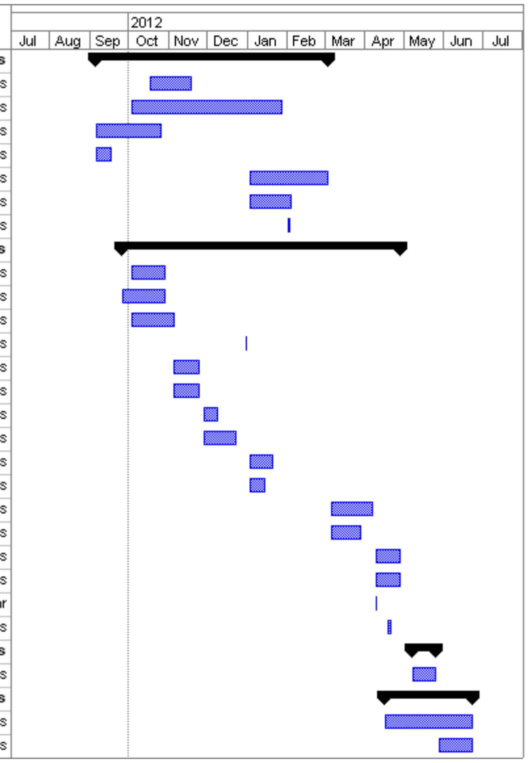
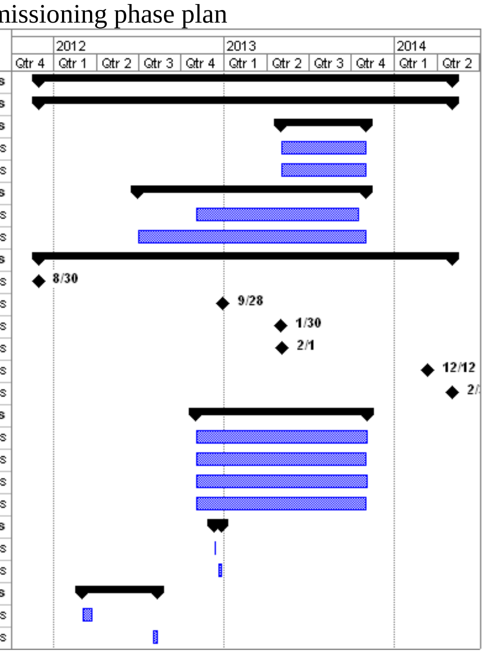
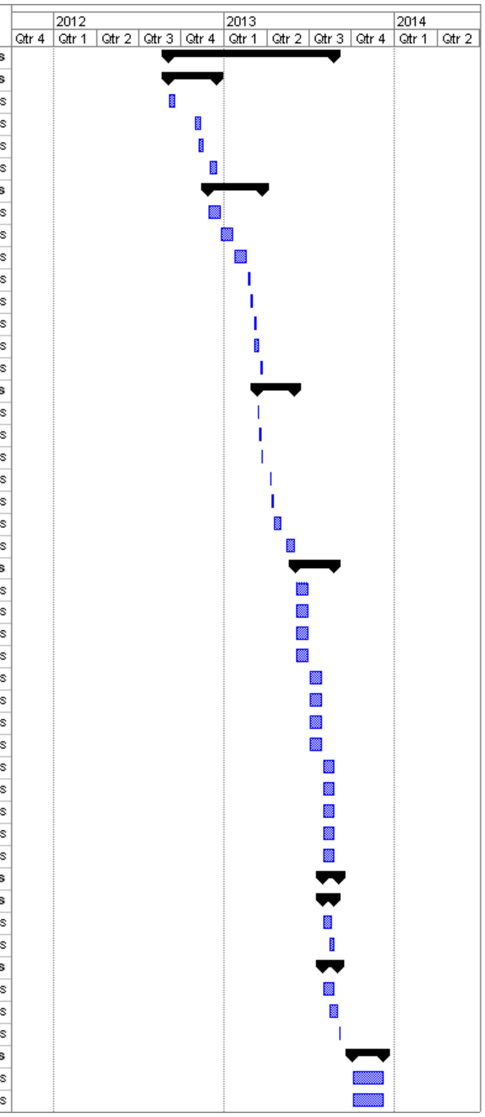


Figure 12: WMKO delivery and commissioning phase plan

ID	WBS	Task Name	Work
1	1	Keck I TT Facility	**2,242 hrs**
2	1.1	Project Management	**142 hrs**
3	1.1.1	Planning & Tracking	**32 hrs**
4	1.1.1.1	Cost Update	16 hrs
5	1.1.1.2	Schedule Update	16 hrs
6	1.1.2	Meetings	**110 hrs**
7	1.1.2.1	Weekly Engineering Meetings	100 hrs
8	1.1.2.2	Quarterly Science Meeting	10 hrs
9	1.1.3	Milestones & Design Reviews	**0 hrs**
10	1.1.3.1	Detailed Design Review	0 hrs
11	1.1.3.2	TTF Sensor Pre-Ship Review	0 hrs
12	1.1.3.3	Pre-Summit Review	0 hrs
13	1.1.3.4	Readiness for 13B Shared Risk Review	0 hrs
14	1.1.3.5	Handover Review	0 hrs
15	1.1.3.6	TAC-allocated Science Starts	0 hrs
16	1.2	Systems Engineering	**60 hrs**
17	1.2.1	Verification and documentation of requirements compliance/non-c	20 hrs
18	1.2.2	Verification and documentation of interface compliance/non-comp	20 hrs
19	1.2.3	Documentation of ECR completion	12 hrs
20	1.2.4	Update of performance predictions and budgets with "as built" pa	8 hrs
21	1.3	HQ Preparation	**56 hrs**
22	1.3.1	Pre-Telescope/Summit Readiness Review	20 hrs
23	1.3.2	Package & transport systems to summit	36 hrs
24	1.4	Telescope Preparation	**240 hrs**
25	1.4.1	Bench Modifications	128 hrs
26	1.4.2	Facility Modifications	112 hrs



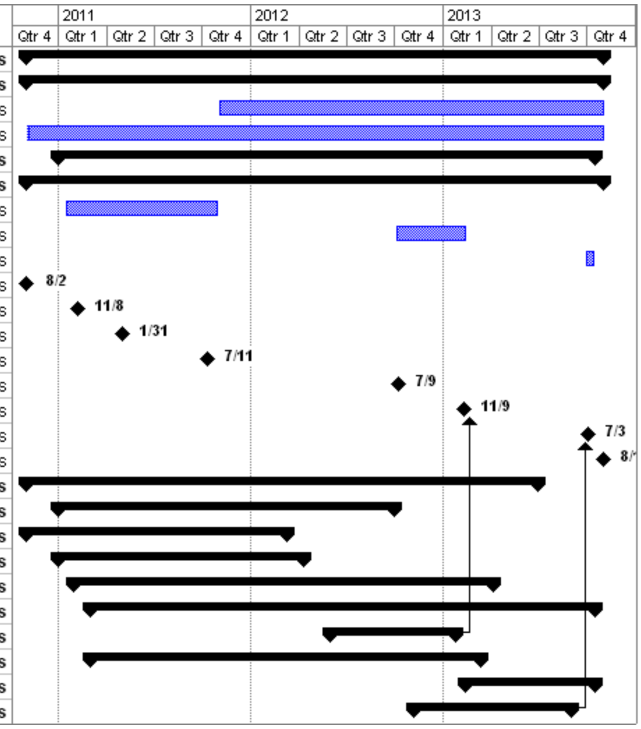
ID	WBS	Task Name	Work
27	1.5	Telescope I&T	**1,416 hrs**
28	1.5.1	Installation	**426 hrs**
29	1.5.1.1	RTC Installation and Test	36 hrs
30	1.5.1.2	Controls and Observing Software Installation	80 hrs
31	1.5.1.3	Camera Controls Installation	30 hrs
32	1.5.1.4	Opto-Mechanical + Camera Installation and Alignment	280 hrs
33	1.5.2	Daytime I&T	**580 hrs**
34	1.5.2.1	Verify each subsystem's performance	140 hrs
35	1.5.2.2	Verification of Interfaces	140 hrs
36	1.5.2.3	System I&T	140 hrs
37	1.5.2.4	Pupil alignment check	20 hrs
38	1.5.2.5	Distortion map	20 hrs
39	1.5.2.6	Flat field calibration using the dome flats	20 hrs
40	1.5.2.7	Closed loop TT operation & optimization	80 hrs
41	1.5.2.8	Dithering, nodding and repositioning using the fiber	20 hrs
42	1.5.3	On-sky I&T	**202 hrs**
43	1.5.3.1	Verify camera orientation and scale	20 hrs
44	1.5.3.2	Acquisition time and performance	20 hrs
45	1.5.3.3	Tip tip offload testing	20 hrs
46	1.5.3.4	Verify DAR operation	20 hrs
47	1.5.3.5	Verify Dithering, nodding and repositioning on sky	20 hrs
48	1.5.3.6	Closed loop TT operation & optimization single stars	100 hrs
49	1.5.3.7	Closed loop TT operation multiple stars	2 hrs
50	1.5.4	Performance Characterization	**208 hrs**
51	1.5.4.1	Photometric calibration of the NIR TTS all modes.	20 hrs
52	1.5.4.2	Photometric calibration of the STRAP, LBWFS and CCD	2 hrs
53	1.5.4.3	Emissivity measurement (NIR TTS,OSIRIS+Pickoffs)	20 hrs
54	1.5.4.4	Acquisition time (including tel slew)	20 hrs
55	1.5.4.5	Dither and offsetting time	20 hrs
56	1.5.4.6	Repositioning accuracy	20 hrs
57	1.5.4.7	Strehl ratio on the NIR TTS	20 hrs
58	1.5.4.8	Statistical study of number of suitable TT stars	2 hrs
59	1.5.4.9	Ensquared energy in a 50 mas OSIRIS spaxel	20 hrs
60	1.5.4.10	Strehl ratio on OSIRIS	20 hrs
61	1.5.4.11	EE and Strehl ratio with STRAP & K1AO	2 hrs
62	1.5.4.12	Characterize LBWFS perform. Limits	2 hrs
63	1.5.4.13	Documentation of performance	40 hrs
64	1.6	Commissioning and Handover	**248 hrs**
65	1.6.1	Training of operation personnel	**116 hrs**
66	1.6.1.1	Training for AO ops lead and SA	64 hrs
67	1.6.1.2	Training of support team engineering disciplines Opt, ME, EE,	52 hrs
68	1.6.2	Documentation of NIRTTS system	**112 hrs**
69	1.6.2.1	Update LGS web page	20 hrs
70	1.6.2.2	Produce documentation and update on Keck share	92 hrs
71	1.6.3	Handover review	20 hrs
72	1.7	Science Verification	**80 hrs**
73	1.7.1	Galactic Center	40 hrs
74	1.7.2	Gravitational Lensing	40 hrs



9. Proposal Plan (for reference)

A rolled up version of the project plans, as submitted in the NSF ATI proposal, showing key milestones and work estimates is provided in Figure 13. The rolled up proposal project plan for the camera system to be built at COO is also shown at the bottom of Figure 13 (note that this includes 276h of Stalcup which is already accounted for in the overall project plan).

ID	WBS	Task Name	Work
1	1	**Keck I TTS Facility**	**7,210 hrs**
2	1.1	**Project Management**	**1,650 hrs**
3	1.1.1	Planning	280 hrs
4	1.1.2	Management & Reporting	500 hrs
5	1.1.3	**Travel**	**120 hrs**
9	1.1.4	**Milestones & Design Reviews**	**750 hrs**
10	1.1.4.1	Design Review Support	350 hrs
11	1.1.4.2	Pre-Ship Review Support	300 hrs
12	1.1.4.3	Handover Review Support	100 hrs
13	1.1.4.4	Project Start	0 hrs
14	1.1.4.5	System Design Review	0 hrs
15	1.1.4.6	Preliminary Design Review	0 hrs
16	1.1.4.7	Detailed Design Review	0 hrs
17	1.1.4.8	TTF Sensor Pre-Ship Review	0 hrs
18	1.1.4.9	Pre-Summit Review	0 hrs
19	.1.4.10	Handover Review	0 hrs
20	.1.4.11	TAC-allocated Science Starts	0 hrs
21	1.2	**Systems Engineering**	**600 hrs**
26	1.3	**NIR TT Sensor Camera**	**0 hrs**
40	1.4	**Opto-mechanics**	**890 hrs**
57	1.5	**Controls**	**760 hrs**
76	1.6	**Operations Software**	**960 hrs**
86	1.7	**Integration, Test & Commissioning**	**2,030 hrs**
87	1.7.1	**Laboratory I&T**	**570 hrs**
100	1.7.2	**AO Facility Modifications**	**300 hrs**
106	1.7.3	**Telescope I&T**	**1,160 hrs**
119	1.8	**Operations Handover**	**320 hrs**



ID	WBS	Task Name	Work
1	1.3	**NIR TT Sensor Camera**	**7,572.4 hrs**
2	1.3.1	**Project management, meetings & reviews**	**936 hrs**
54	1.3.2	**Systems engineering**	**312 hrs**
64	1.3.3	**Design**	**972 hrs**
94	1.3.4	**Procurement and Fabrication**	**3,080.4 hrs**
152	1.3.5	**System integration and test at Caltech**	**1,712 hrs**
174	1.3.6	**Commisioning support at Keck**	**560 hrs**

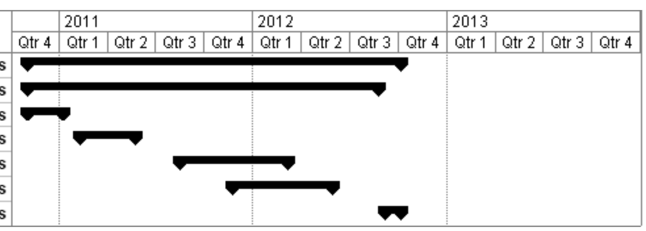


Figure 13: Full project plan, proposal version, excluding the TTS camera (top). TTS camera plan (bottom)

The COO labor estimates in WBS 1.3 were updated to reflect the contingency reduction required to meet the revised NSF budget, some work transferred to WMKO and Microgate, the work already completed during the system design which was charged to NGAO and the addition of a filter mechanism. The WMKO labor estimate were not updated since the dollars removed to meet the revised NSF budget were taken from labor dollar contingency, not labor hours.