Keck Adaptive Optics Note 839

Near-Infrared Tip-Tilt Sensor
Systems Engineering Management Plan

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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 NIR TTS system to be implemented with the Keck I LGS AO system.

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 will act 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. Chris Neyman will be added to the project team for at least the preliminary design phase to provide systems engineering support and to help define the operations software tools. Andrew Cooper will replace Ed Wetherell during the preliminary design phase.

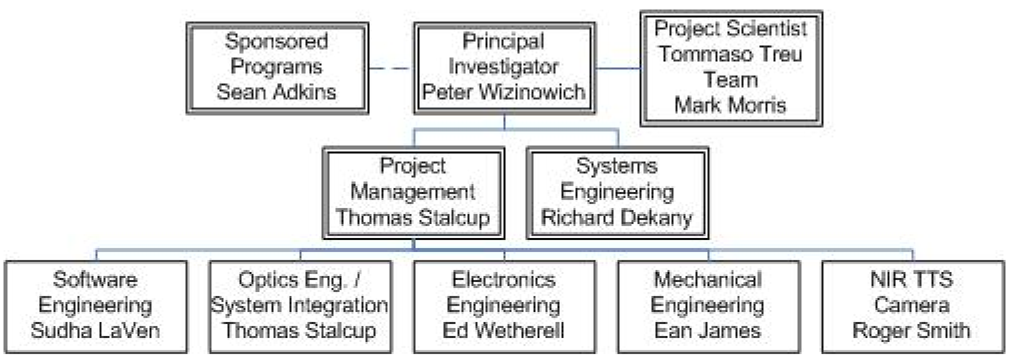


Figure 1: Project Organization

Table 1: Project Staff

Position	Name	Notes
Principal Investigator	Peter Wizinowich	As PI & AO project manager Wizinowich is responsible for the overall project success in coordination with other WMKO activities.
Project Scientist	Tommaso Treu	Leads the management of the science requirements for the upgrade and oversees the performance characterization phase of the project.
Project Manager	Thomas Stalcup	Responsible for managing the engineering team & project to meet the budget and schedule. Also leads the optical design, system integration and performance characterization.
Systems Engineer	Richard Dekany	Manages the design process to ensure proper design choices and maintains the performance budgets.
NIR TTS Camera Lead	Roger Smith	Responsible for the design and delivery of the NIR sensor, including readout mode validation and lab performance testing.
Leads: James (mechanical), LaVen (software) & Wetherell (electronics)		Engineering leads design and lead modifications to the hardware and software systems and design/specify additional components required for the upgrade.

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.

Table 2: Product breakdown structure

PBS Level 1	Level 2	Level 3
Camera System	Camera Hardware	Camera Optics and baffles
		Filter Change Mechanism
		Filter Stage Motor, Limit Switches & Cable
		Cryostat: vacuum enclosure, window, radiation shields
		Cryotiger
		Detector and mount
		Temperature sensor and heaters
		Dessicant
		Getter or ion pump
	Readout Electronics	ARC Timing Board
		ARC Video Card
		ARC clock generator
		Interface to Dewar
		Interface to Host Computer
		Interface to RTC
		Electromnics Enclosure and mounting hardware
		Cooling system for electronics
	Housekeeping Electronics	Ion gauge controller
		Temperature Controller and cables
		Interface to Host Computer - Terminal Server

	External Cryo System	Compressor and gas lines for cryocooler
		Compressed gas lines.
	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)
	Focus Mechanism	Riser for Focus Stage
		Focus Stage
		Focus Stage Motor, Encoder & Cable
		Interface Plate
		Field Lens & Mount
		Fold Mirror & Mount
		Riser for Camera
		Camera Interface Plate
	Camera tip-tilt mechansim	External pivots and screw adjustment for camera to locate internal pupil at cold stop.
	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

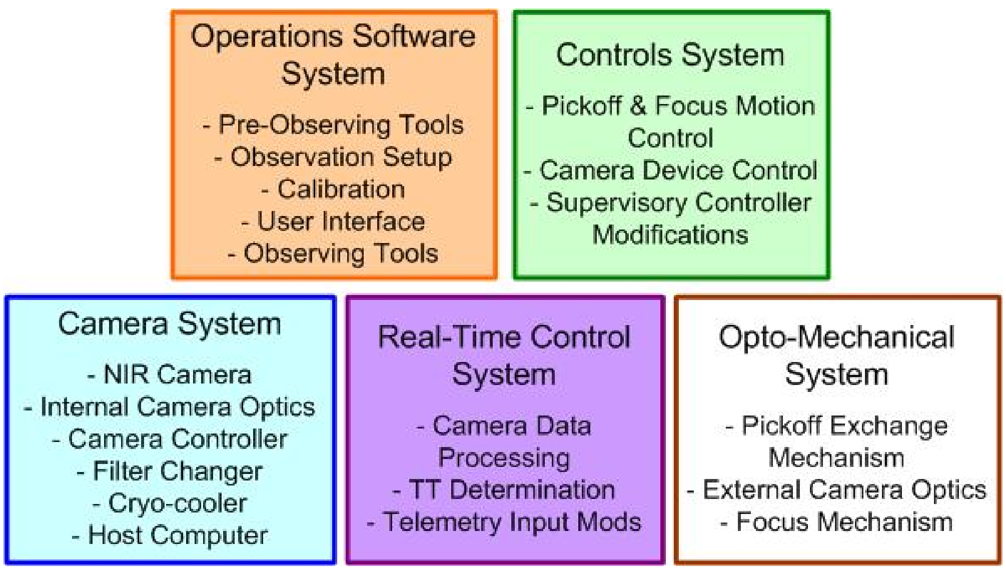


Figure 2: Block diagram summary of major NIR TTS subsystems and their key components

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 1.6 correspond to level 1 of the PBS with one exception; since the real-time control system is sub-contracted this is included under the umbrella of the controls WBS.

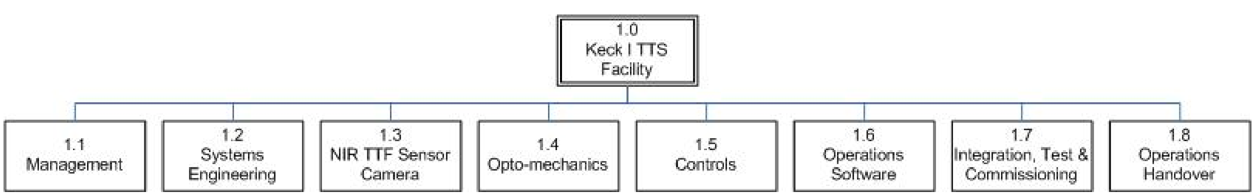


Figure 3: Top-level work breakdown structure

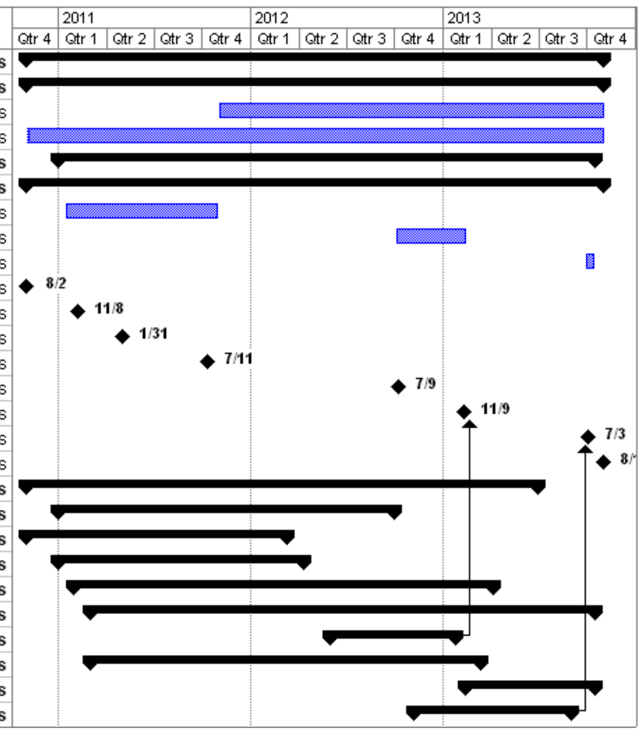
4.2 Project Plan

A rolled up version of the project plan showing key milestones and work estimates is provided in Figure 4. The rolled up project plan for the NIR TTS camera to be built at COO is also shown at the bottom of Figure 4. Both of these project plans are expanded in section 9. The schedule has not been updated from the project plan included with the proposal. The dates were considered to be sufficient for the SDR.

The COO labor estimates in WBS 1.3 have been 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 has not been updated for the SDR since the dollars removed to meet the revised NSF budget were taken from labor dollar contingency, not labor hours.

During the system design phase a more detailed preliminary design phase plan was developed and is presented in section 4.3. A revised project plan, based on a better understanding of the project, will be produced for the PDR.

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**	**6,022.4 hrs**
2	1.3.1	**Project management, meetings & reviews**	**834 hrs**
54	1.3.2	**Systems engineering**	**128 hrs**
64	1.3.3	**Design**	**1,012 hrs**
95	1.3.4	**Procurement and Fabrication**	**2,684.4 hrs**
155	1.3.5	**System integration and test at Caltech**	**1,060 hrs**
178	1.3.6	**Commisioning support at Keck**	**304 hrs**

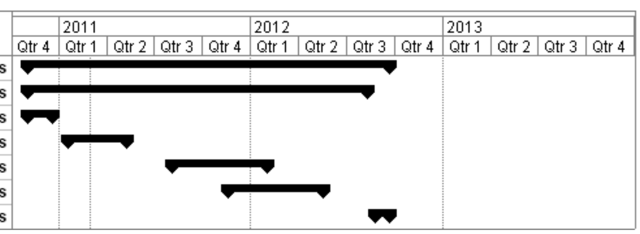


Figure 4: Full project plan excluding the TTS camera (top figure). TTS camera plan (bottom)

WMKO's standard development process will be followed. This includes system, preliminary and detailed design phases for the new elements. Modifications to existing hardware and software will be handled through the Observatory's engineering change control process. An iterative approach will be taken to the software development with coding occurring throughout the design and implementation phases.

The implementation phase will include fabrication and testing of the NIR TTS camera at CIT before a pre-ship review and fabrication of the new hardware and software to implement this camera with the AO system at WMKO. Most of the CIT and WMKO hardware and software components will be integrated for a laboratory testing phase at WMKO headquarters prior to moving the system to the telescope. Modifications to the Keck I AO facility to support the installation will be performed during the fabrication and laboratory testing phases. A readiness review will be held prior to installing the new TTS system at the telescope. The telescope integration and testing phase will include performance characterization and some initial shared-risk science support. Operations personnel will participate in the laboratory and telescope integration and test, and especially the commissioning phase, in support of knowledge transfer to the people with operational responsibility. Operational system changes will go through engineering review by the AO configuration control board.

4.3 Preliminary Design Phase Plan

A spreadsheet listing the preliminary design phase tasks and effort estimates is shown in Table 3. The relevant WBS number and name is provided in the first two columns. The specific tasks are listed in column 2. The initials of the person leading each task are provided in the 3rd column. The effort estimate (hours) for each WMKO and COO participant, identified by initials, is listed beside each task, followed by the overall total hours. The last two columns show the number of hours identified in the proposal plan for each high level WBS element.

A few calculations are done near the bottom of the spreadsheet. For each individual the number of work hours and weeks is totaled. The percentage of each individual's time is then calculated assuming 12 weeks for the preliminary design. The number of hours by individual during the SD phase is a sum of the actuals worked through October plus an estimate through the SDR.

This estimate of the hours for the preliminary design is compared to the proposal estimate in the bottom right hand corner of the spreadsheet. The total WMKO and COO design hours in the proposal plan is listed first (2257 and 1478 hours, respectively). The percentage of these total hours spent on the SD phase and estimated for the PD phase is then calculated, with the remainder left for the DD phase. This is intended as a sanity check on our PD estimate and to determine whether a reasonable distribution of hours is being spent on the three design phases. WMKO appears to be relatively heavy in the PD phase and COO a little light in the SD phase. This seems reasonable given the nature of the work. WMKO needs to be sure to define the task well in the SD and PD phases and to largely complete the optical design and the software definition in the PD phase. COO will still have a lot of detailed fabrication drawings to prepare in the DD phase, whereas WMKO has few of these to prepare.

The WMKO personnel for the PD phase have been changed somewhat versus the FY11 plan shown in section 6 due to personnel availability. Since Stalcup (TS) needs to stay focused on the K1 LGS free space transport effort he has largely been replaced by a combination of Neyman (CN) and Wizinowich (PW) for the PD phase. For similar reasons, Wetherell (EW) has been replaced by Cooper (AC) for the PD phase. Conrad is departing WMKO and he has been replaced with Lyke (JL).

The Microsoft project plan for the PD phase at WMKO is shown in Figure 5. The same personnel as shown in Table 3 have been input into this plan and these personnel have been adequately leveled. The PDR date with this schedule is shown as March 23, 2011. This corresponds to a 2 month slip with respect to the proposal schedule; an additional month to the 1 month of slip at the SDR.

Table 3: Preliminary design phase tasks & personnel estimates

			WMKO										COO								Proposal	
WBS	**Task**	**Lead**	**EJ**	**SK**	**SL**	**JL**	**CN**	**TS**	**PS**	**CT**	**PW**	**AC**	**RB**	**JC**	**RD**	**DH**	**GR**	**RS**	**Total**	**Due Date**	**WMKO**	**COO**
1.1	*Project Management*																				475	234
	Weekly Engineering Meetings (~10)	PW			5	4	10	5			20	3			10			10	67	3/18/11		
	Quarterly Science Meeting (~1)	PW				1	1				4								6	1/18/11		
	Cost Estimate Update	PW/RS	4		4		4				16	4			4			8	44	3/11/11		
	Schedule Update	PW	2		4		2				16	2			4			16	46	3/14/11		
	Risk Update	PW			2		2				8	2			2			2	18	3/11/11		
	SEMP Update	PW			2		2				24	2			8			2	40	3/15/11		
	PDR preparations	PW	4		4		4			4	16	4			4			16	56	3/22/11		
	PDR	PW	4		6		6	6		4	6	6			6			6	50	3/23/11		
1.2.1	*System Architecture Design*																				280	
	Tip-tilt Performance Predictions	MvD/PW									10								10	1/28/11		
	Thruput/Emiss/SNR Budget Updates	CN					16				1								17	2/11/11		
	Error Budget Update	RD					4				1				36				41	2/25/11		
	Design Manual Update	PW	2		16	2	4	8			40	16			8			16	112	3/4/11		
1.2.2	*Requirements Definition*																				120	
	System Requirement Updates	CN					4												4	1/21/11		
	Observing Operations Concept Document	CN				16	16				4								36	1/7/11		
	Camera Functional Requirements Update	RS/CN					2								2			2	6	1/28/11		80
	Opto-Mechanics Functional Req Update	CN					2	2											4	1/28/11		
	Controls Functional Req Update	SL/EW			2		2					2							6	1/28/11		
	Operations Software Req Update	CN			2	2	2	2											8	1/28/11		
1.2.3	*Interface Definition*																				120	
	Camera to AO ICD Updates	PW/RS			2		2					2				8		8	22	1/28/11		192
1.2.4	*Engineering Change Control*																				20	
	AO ECR - draft	PW					4			4									8	2/11/11		
	Electrical ECR - draft	EW								4		4							8	2/11/11		
	Software ECR - draft	SL			4					4									8	2/11/11		
1.3	*NIR TT Sensor Camera Design*																					972
	Self Heating Testing	RS														4		2	6	12/15/10		
	Timing Board Fiber Link Testing	RS														16		4	20	1/5/11		
	Dewar Design Modifications	RS											80					16	96	1/30/11		
	Dewar Snout Design	RS											80					16	96	2/15/11		
	Filter Mechanism Design	RS											20					4	24	1/30/11		
	Optics Mount Design	RS											40					4	44	2/28/11		
	Thermal Control System Design	RS											32					4	36	2/28/11		
	Dewar Electronics Design	RS															40	4	44	2/28/11		
	Camera Control Software Design	RS												60		150		4	214	2/28/11		
1.4	*Opto-mechanics Design*																				632	
	Optics Design Updates	TS						40											40	12/31/11		
	Optics Design Tolerancing	TS						40											40	1/28/11		
	Dichroic Quotes	PW								6	2								8	1/28/11		
	Optics Quotes	TS					8	2		8									18	2/25/11		
	Alignment Plan Details	PW									16								16	2/11/11		
	Optical Pickoff Mech Design	EJ	40								2								42	1/7/11		
	Camera Assembly Mech Design	EJ	40								2								42	2/4/11		
	AO Bench Mods Mech Design	EJ	40								2								42	1/28/11		
1.5	*Controls System Design*																				290	
	OBS Motion Control Hardware	AC										40							40	1/14/11		
	OBS Motion Control Software	SL			20														20	1/19/11		
	OBS Device Control Hardware	AC										20							20	2/4/11		
	OBS Device Control Software	SL			60														60	1/28/11		
	Differential Atmospheric Refraction Mods	SL			8				16										24	1/21/11		
	Focus Compensation Mods	SL			8				16										24	1/21/11		
	Non-Sidereal Tracking (goal)	SL																	0			
	Rotator Control (long term goal)	SL																	0			
	Wavefront Controller Command Proc Mod	SL			2														2	1/28/11		
	Microgate Contract Design Support	SL			120		4	2			8	2				8		20	164	3/18/11		
1.6	*Operations Software Design*																				320	
	Acquisition Planning Tool	JL		2		12	8												22	1/14/11		
	Performance Estimation Tool	CN				4	40												44	2/4/11		
	Setup Tool Mods	CN				2	8												10	2/4/11		
	Camera Calibrations	CN				2	8												10	1/7/11		
	Focusing Calibration	CN					4												4	1/7/11		
	Distortion Mapping	CN				2	8												10	1/7/11		
	User Interfaces	JL				16	8												24	2/11/11		
	Acquisition	CN		8		4	4												16	1/21/11		
	Nodding, Dithering, Repositioning	JL				4	8												12	1/28/11		
	Background Measurement	CN				2	16												18	1/28/11		
	FITS Header	JL				2													2	2/4/11		
	Telemetry Recorder System	SL			16		2												18	2/18/11		
1.7	*Integration, Test & Commissioning*																					
	Draft Plan	PW									16								16	1/28/11		
1.8	*Operations Handover*																					
	Draft Plan	PW				4					4								8	1/28/11		
			EJ	**SK**	**SL**	**JL**	**CN**	**TS**	**PS**	**CT**	**PW**	**AC**	**RB**	**JC**	**RD**	**DH**	**GR**	**RS**			**WMKO**	**COO**
	Total (hrs) =		136	10	287	79	215	107	32	34	218	109	252	60	84	186	40	164	2013	Proposal est.	2257	1478
	Total (wks) =		3.4	0.3	7.2	2.0	5.4	2.7	0.8	0.9	5.5	2.7	6.3	1.5	2.1	4.7	1.0	4.1	50.3	SD estimate	25%	10%
	% assuming 12 work weeks (14 calendar) =		28%	2%	60%	16%	45%	22%	7%	7%	45%	23%	53%	13%	18%	39%	8%	34%		PD plan	54%	53%
	SD estimate total (hrs) =		158	0	44	4	40	92	0	8	201	20	10	10	58	4	0	73		DD remainder	21%	36%

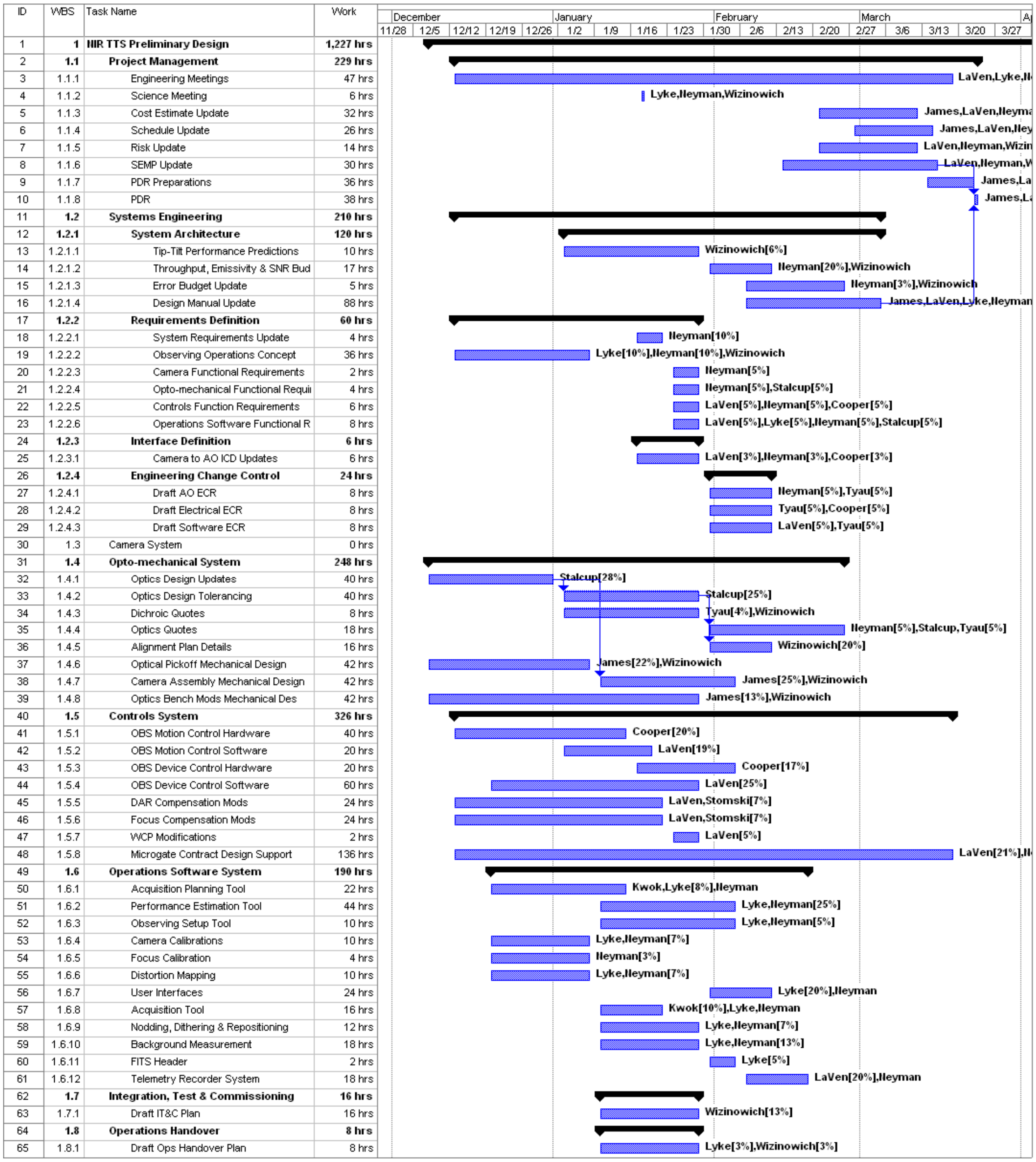


Figure 5: Preliminary design phase project plan

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).

5.2 Budget Actuals

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 include 138 hours of WMKO labor in October (56.5h James, 4.5h LaVen, 52h Stalcup, 2h Wetherell and 22.5h Wizinowich). The total October labor dollars was $10,369 or 6% of the total dollars budgeted for WMKO labor in FY11. In addition there was $250,000 to Teledyne for the H2RG detector and $5,703 for indirect costs. In October Caltech personnel worked 25.5 hours on this project (10.5h Dekany and 15h Smith), again charged to the NGAO technical risk reduction budget.

One additional procurement has been placed and the parts have been 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 COO Budget Changes

We have revised the COO labor hour estimate and budget, as shown in WBS 1.3 of Figure 4. The hours were reduced by 1550 hours to 6022.4 hours as discussed in section 4.2, for a reduction in labor costs of $117, 698. The procurement costs were increased by $1,500 for the filter mechanism, while the H2RG and the ARC procurement that have already been made, plus the dewar optics procurements were transferred from COO to WMKO. Travel was reduced to two trips from four.

5.4 WMKO Budget Changes

We have not redone the WMKO revised proposal labor hour estimate for the SDR because it was already considered to be at a system design level, with the exception of inadequate contingency. For the updated budget we have simply subtracted the actual labor dollars from the revised plan labor dollars to determine the remaining labor dollars. We will work to identify some clear savings during the preliminary design phase in order to carry adequate contingency for the remainder of the project. In the meantime all requirement goals will be assumed not to be deliverables unless they have no budget impact or an overall PDR-level budget is developed that can include specific goals with sufficient project contingency. We will also continue to leverage our collaborations (e.g. GMT) to perform some of the required analysis tasks.

The WMKO procurement budget has been updated to reflect the procurement transfers from COO.

We have received a fixed price quotation from Microgate for $67.8k that has been included in the updated budget. This represents a $44.7k increase over the revised proposal budget but this is largely due to interface work moving from COO to Microgate.

5.5 Budget at SDR

The overall project budget at SDR is presented in Table 4 by year. The total budget (row J) is $1,717k. Again, there is an additional $43k and 483h of support astronomer time provided by WMKO toward offsetting the NSF budget reduction; the support astronomer time is assigned to tasks already and is not available as contingency. This only leaves $42k of contingency (or 3.0% contingency on remaining costs).

Table 6 is the COO project budget which is listed as a subaward in the overall project budget.

The dollars by year for the senior personnel is shown in section A of Table 4 and Table 6. Table 5 and Table 7 provide the same detail for the other personnel on the project.

The equipment purchases over $5k are listed in section B of Table 4 and Table 6 by year. Similar detail for the materials and supplies shown in section G are provided in Table 8 and Table 9.

Table 4: Overall project budget

Expenses	Title	Person Months	Notes	Year One ACTUAL 8/1/10 9/30/10	Year Two ACTUAL 10/01/10 11/21/10	Year Two 11/22/10 09/30/11	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	$ 8,145	$ 15,809	$ 7,830	$ 8,717	$ 44,740
T. Stalcup	Project Manager	15		$ 670	$ 6,258	$ 26,201	$ 35,702	$ 47,555	$ 116,386
(2) Total Senior Personnel		18	1	**$ 4,909**	**$ 14,403**	**$ 42,010**	**$ 43,532**	**$ 56,272**	**$ 161,126**
B. Other Personnel									
(0) Post Doctoral Associates				$ -		$ -	$ -	$ -	$ -
(9) Other Professionals		23	1	$ 4,922	$ 5,995	$ 88,192	$ 66,630	$ 35,339	$ 201,078
(0) Graduate Students				$ -		$ -			$ -
(0) Undergraduate Students				$ -		$ -			$ -
(1) Secretarial - Clerical (If Charged Directly)			1	$ -		$ -	$ -	$ -	$ -
(0) Other				$ -					$ -
Total Salaries and Wages				**$ 9,831**	**$ 20,398**	**$ 130,202**	**$ 110,162**	**$ 91,611**	**$ 362,204**
C. Fringe Benefits			2	$ 2,320	$ 5,263	$ 33,592	$ 28,091	$ 23,332	$ 92,599
Total Salaries, Wages and Fringe Benefits				**$ 12,151**	**$ 25,661**	**$ 163,794**	**$ 138,253**	**$ 114,943**	**$ 454,803**
D. Equipment									
H2RG detector				$ -	$ 250,000			$ -	$ 250,000
ARC SDSU-III readout electronics				$ -	$ 6,000				$ 6,000
Microgate RTC modifications				$ -		$ 27,120	$ 40,680		$ 67,800
Dewar optics				$ -		$ 10,000	$ 13,000		$ 23,000
Dichroic beamsplitter				$ -		$ -	$ 11,000		$ 11,000
Host computer				$ -		$ 5,500	$ -		$ 5,500
Single board computer				$ -		$ 5,500	$ -		$ 5,500
Focus stage				$ -		$ -	$ 6,600	$ -	$ 6,600
Total Equipment				**$ -**	**$ 256,000**	**$ 48,120**	**$ 71,280**	**$ -**	**$ 375,400**
E. Travel									
Domestic			3	$ -		$ 2,066	$ 4,000	$ -	$ 6,066
Foreign				$ -		$ -	$ -	$ -	$ -
F. Other Supplies				$ -		$ -	$ -	$ -	$ -
G. Other Direct Costs									
1. Materials and Supplies				$ 331	$ 44	$ 13,375	$ 14,300	$ 2,200	$ 30,250
2. Publication Costs/Documentation/Dissemination				$ -		$ -	$ -	$ -	$ -
3. Consultant Services				$ -		$ -	$ -	$ -	$ -
4. Computer Services				$ -		$ -	$ -	$ -	$ -
5. Subawards	CIT		4	$ -	$ -	$ 405,105	$ 149,730	$ -	$ 554,835
6. Other				$ -		$ -	$ -	$ -	$ -
Total Other Direct Costs				**$ 331**	**$ 44**	**$ 418,480**	**$ 164,030**	**$ 2,200**	**$ 585,085**
H. Total Direct Costs				**$ 12,482**	**$ 281,705**	**$ 632,460**	**$ 377,563**	**$ 117,143**	**$ 1,421,354**
I. Indirect Costs (F&A)									
Modified total direct costs (Base)			5	$ 12,482	$ 25,705	$ 179,236	$ 156,553	$ 117,143	$ 491,119
Rate		60.00%		$ 6,865	$ 17,438	$ 106,150	$ 93,932	$ 70,286	$ 294,671
Total Indirect Costs				**$ 6,865**	**$ 17,438**	**$ 107,541**	**$ 93,932**	**$ 70,286**	**$ 296,062**
J. Total Direct and Indirect Costs				**$ 19,347**	**$ 299,143**	**$ 740,002**	**$ 471,495**	**$ 187,429**	**$ 1,717,417**
WMKO cost share							$ 15,000	$ 28,000	$ 43,000
Revised Proposal Funding Profile				$ 314,511		$ 715,613	$ 498,447	$ 187,429	$ 1,716,000
Budget (Proposal + WMKO) - Plan				$ 295,164	$ (299,143)	$ (24,389)	$ 41,952	$ 28,000	**$ 41,583**

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 5: Other WMKO Professionals

	Person-Months	FY10	FY11	FY12	FY13	Totals
Mechanical Engineer	1.3	$ -	$ 4,066	$ 7,256	$ -	$ 11,322
Support Astronomer	0.0	$ -	$ -	$ -	$ -	$ -
Software Engineer	10.4	$ 2,824	$ 40,439	$ 32,206	$ 15,718	$ 91,187
Bell-Mechanical Eng	4.2	$ 498	$ 31,233	$ 4,607	$ 294	$ 36,632
Wetherell-Electronics	1.5	$ -	$ 10,731	$ 1,628	$ 999	$ 13,358
Campbell-AO Ops Mgr	0.8	$ -	$ 4,692	$ 2,126	$ -	$ 6,818
L Chock-Software Eng	1.0	$ -	$ 2,259	$ 1,723	$ 5,287	$ 9,270
Cooper-Electronics Eng	0.5	$ -	$ -	$ -	$ 4,112	$ 4,112
Martin-AO Eng	0.8	$ -	$ -	$ 2,170	$ 4,817	$ 6,987
Elec support	2.4	$ -	$ 2,366	$ 14,914	$ 4,112	$ 21,393
Total =	22.8	$ 3,322	$ 95,787	$ 66,630	$ 35,339	$ 201,078

Table 6: Detailed CIT Project Budget (incorporated on line G.5 of Table 4)

Expenses	Title	Person Months	Notes	Year One 8/1/10 9/30/10	Year Two 10/01/10 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		$ -	$ 24,684	$ 8,799	$ -	$ 33,484
R. Smith	NIR TTS Camera Lead	8		$ -	$ 43,533	$ 43,617	$ -	$ 87,149
(2) Total Senior Personnel		11	1	**$ -**	**$ 68,217**	**$ 52,416**	**$ -**	**$ 120,633**
B. Other Personnel								
(0) Post Doctoral Associates				$ -	$ -	$ -	$ -	$ -
(7) Other Professionals		30	1	$ -	$ 178,369	$ 51,134	$ -	$ 229,504
(0) Graduate Students				$ -	$ -			$ -
(0) Undergraduate Students				$ -	$ -			$ -
(0) Secretarial - Clerical (If Charged Directly)			1	$ -	$ -	$ -	$ -	$ -
(0) Other				$ -				$ -
Total Salaries and Wages				**$ -**	**$ 246,586**	**$ 103,551**	**$ -**	**$ 350,137**
C. Fringe Benefits			2	$ -	$ 62,879	$ 26,405	$ -	$ 89,285
Total Salaries, Wages and Fringe Benefits				**$ -**	**$ 309,466**	**$ 129,956**	**$ -**	**$ 439,422**
D. Equipment								
Cryocooler					$ 15,000	$ -		$ 15,000
Lakeshore controller				$ -	$ 6,000	$ -		$ 6,000
ARC SDSU-III readout system					$ 22,500	$ -		$ 22,500
Total Equipment				**$ -**	**$ 43,500**	**$ -**	**$ -**	**$ 43,500**
E. Travel								
Domestic			3	$ -	$ -	$ 3,960		$ 3,960
Foreign				$ -	$ -	$ -	$ -	$ -
F. Other Supplies				$ -	$ -	$ -	$ -	$ -
G. Other Direct Costs								
1. Materials and Supplies				$ -	$ 14,100	$ 10,000	$ -	$ 24,100
2. Publication Costs/Documentation/Dissemination				$ -	$ -	$ -	$ -	$ -
3. Consultant Services				$ -	$ -	$ -	$ -	$ -
4. Computer Services				$ -	$ -	$ -	$ -	$ -
5. Subawards				$ -	$ -	$ -	$ -	$ -
6. Other - shop fees for Fabrication				$ -	$ 30,096	$ -	$ -	$ 30,096
Total Other Direct Costs				**$ -**	**$ 44,196**	**$ 10,000**	**$ -**	**$ 54,196**
H. Total Direct Costs				**$ -**	**$ 397,162**	**$ 143,916**	**$ -**	**$ 541,078**
I. Indirect Costs (F&A)								
Modified total direct costs (Base)					$ -	$ -	$ -	$ -
Rate		62.00%		$ -	$ -	$ -	$ -	$ -
Total Indirect Costs				**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
J. Total Direct and Indirect Costs				**$ -**	**$ 397,162**	**$ 143,916**	**$ -**	**$ 541,078**
Revised Proposal Funding Profile				$ 275,034	$ 379,103	$ 209,462	$ -	$ 863,599

Table 7: Other CIT Professionals

	Person-Months	FY10	FY11	FY12	FY13	Totals
Gustavo Rahmer	5	$0	$24,505	$30,450	$0	$54,955
David Hale	6	$0	$40,915	$4,026	$0	$44,941
John Cromer	7	$0	$59,260	$11,335	$0	$70,595
Ernest Cromer	1	$0	$10,573	$0	$0	$10,573
Khanh Bui	3	$0	$35,027	$3,038	$0	$38,065
Viswa Velur	1	$0	$4,571	$2,285	$0	$6,856
Jason Fucik	0	$0	$3,519	$0	$0	$3,519
Total =	23	$0	$178,369	$51,134	$0	$229,504

Table 8: WMKO Materials and Supplies (unit cost under $5k)

WBS	Item	FY11	FY12	FY13	Totals
1.4.3.1	Annular mirror		$2,200		$2,200
1.4.3.1	Pickoff fab	$3,300			$3,300
1.4.3.1	Pickoff stage	$4,400			$4,400
1.4.3.3	Dewar mount		$1,650		$1,650
1.4.3.2	Field lens assembly	$1,100			$1,100
1.4.3.4	Telescope simulator optics/mounts	$2,750	$2,750		$5,500
1.4.3.1	Servo amp	$550	$0		$550
1.4.3.3	Servo amp	$550	$0		$550
1.5.1.5	Electronic cabling		$275		$275
1.5.2.4	Electronic cabling		$275		$275
1.7.1.1.3	Camera/computer interface		$1,100		$1,100
1.4.3.1	Vxworks BSP		$3,300		$3,300
1.7.2.2	AO facility power, cooling, mechanical fab		$1,100		$1,100
1.7.2.4	Motion Control Bulkhead mods		$550		$550
	Miscellaneous	$1,100	$1,100	$2,200	$4,400
	Total =	$13,750	$14,300	$2,200	$30,250

Table 9: CIT Materials and Supplies (unit cost under $5k)

	FY11	FY12	FY13	Totals
Pupil mask design & procurement	$ 400			$ 400
fabricate optics mounts	$ 1,000			$ 1,000
Install optics in mounts	$ 200			$ 200
Procure vacuum gauge and controller	$ 2,000			$ 2,000
Procure hermetic connectors	$ 800			$ 800
Purchase sensors and heaters	$ 1,200			$ 1,200
Procure circular connectors fro cables to dewar	$ 1,000			$ 1,000
Procure D connectors within controller	$ 500			$ 500
Purchase Linux server, rack mount	$ 4,000			$ 4,000
Purchase Terminal server, rack mount	$ 1,000			$ 1,000
Purchase Remote power switch	$ 500			$ 500
Pack and ship shipping of hardware		$ 10,000		$ 10,000
Total =	$ 12,600	$ 10,000	$ -	$ 22,600

6. Staffing

The completion of the Keck I laser free space transport system has been impacting the availability of WMKO personnel for the NIR TTS project, especially Stalcup and Wetherell. Wizinowich has been filling in for Stalcup and will need to continue to do so through ~ February 2011. Similarly, the completion of other projects at Caltech has also distracted the Caltech personnel who are now ramping up on this project.

The personnel shortage has delayed the SDR by 1 month. A collaboration with GMT has helped the schedule by providing Marcos van Dam to perform some of the required performance simulations.

The WMKO FY11 plan has the following personnel hours assigned to this project (as noted in section 4.3 some changes have been made at least for the preliminary design phase):

- AO support astronomers: R. Campbell 83h & A. Conrad 77h (we need to have a separate account for this charging since WMKO will cover these costs)
- Mechanical: E. James 572h, M. Pollard 62h
- Electronics: E. Wetherell 232h
- Software: A. Honey 40h, S. LaVen 667h, K. Tsubota 100h
- Optical Systems: T. Stalcup 873h, P. Wizinowich 83h

Dekany has confirmed that the COO personnel required for the preliminary design phase will be available at the levels indicated at the bottom of Table 3.

7. Configuration Control

Documents will be 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.

Engineering change requests (ECRs) will be submitted in order to protect the operational system. Separate ECRs will be submitted through the SEED database with a note indicating 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.

One or more software ECRs will also be submitted for review through the MANTIS database, again making sure to note the affected CCBs.

We intend to submit ECRs for initial review during the preliminary design phase.

8. 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 matrices using these definitions are shown in the next section. 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.

The risk matrix is shown in Figure 6. Table 10 lists the significant technical and programmatic risks that were identified during the system design.

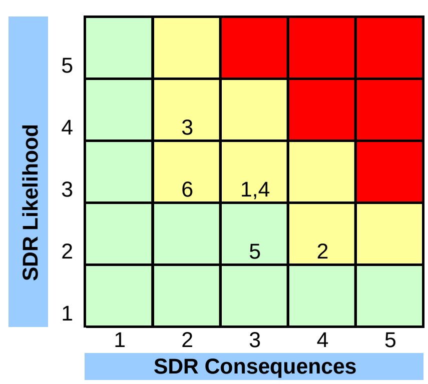


Figure 6: Programmatic and technical risk matrix

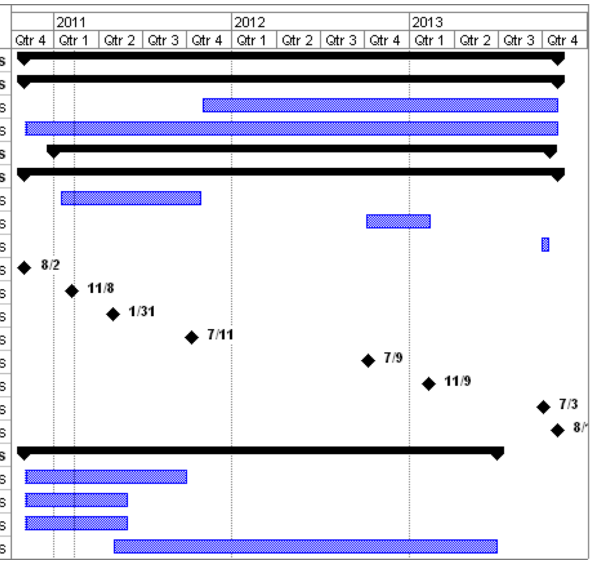
Table 10: Significant risk areas

#	Conse-quence	Like-lihood	Description	SDR Status	PDR Proposed Mitigation
1	3	3	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) Do additional analysis of the correlation algorithm approach to ensure it will meet the requirements. b) Further develop the backup centroiding approach, also being implemented, which would require seeing disk background subtraction &/or Strehl estimation. c) Ensure that the fold mirror in the tip-tilt sensor path could be upgraded with a tracking device to keep 1 star positioned on a quad cell.
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.	Perform additional checks on performance analysis.
3	2	4	Schedule delays due to personnel non-availability	The SDR is 1 month late, & the PDR will likely be ~ 6-8 weeks late, due to personnel still being involved in other projects. Caltech involvement in preparing SDR has been limited. At WMKO issue will extend through ~ Feb/11.	a) At WMKO, more PI involvement & bringing in Neyman. b) At WMKO project priority will significantly increase as K1 free space transport & center launch system are completed in FY11. c) Collaborate with GMT for 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.	a) Perform a more careful cost evaluation for PDR. b) Only accept goals after sufficient budget clearly identified. c) Ensure PD phase stays in budget. d) Test out Microgate interface during PD. e) Review COO SW estimate by mid-Jan.
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 PDR. Longer term we will request adequate implementation gaps & engineering nights. A quick switch back to the operational system is practical.

9. Project Plan Details

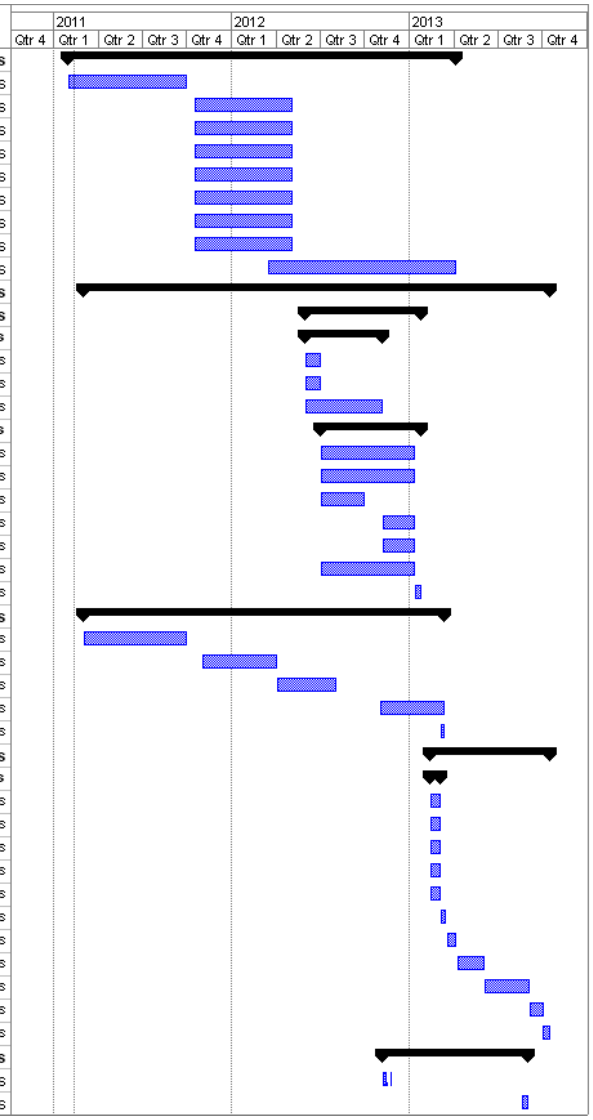
The project plans shown in Figure 4 have been expanded in the following figures.

ID	WBS	Task Name	Work
1	1	**Keck I TT 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**
22	1.2.2	System Architecture Design	280 hrs
23	1.2.3	Requirements Definition	120 hrs
24	1.2.4	Interface Definition	120 hrs
25	1.2.5	Engineering Change Control	80 hrs

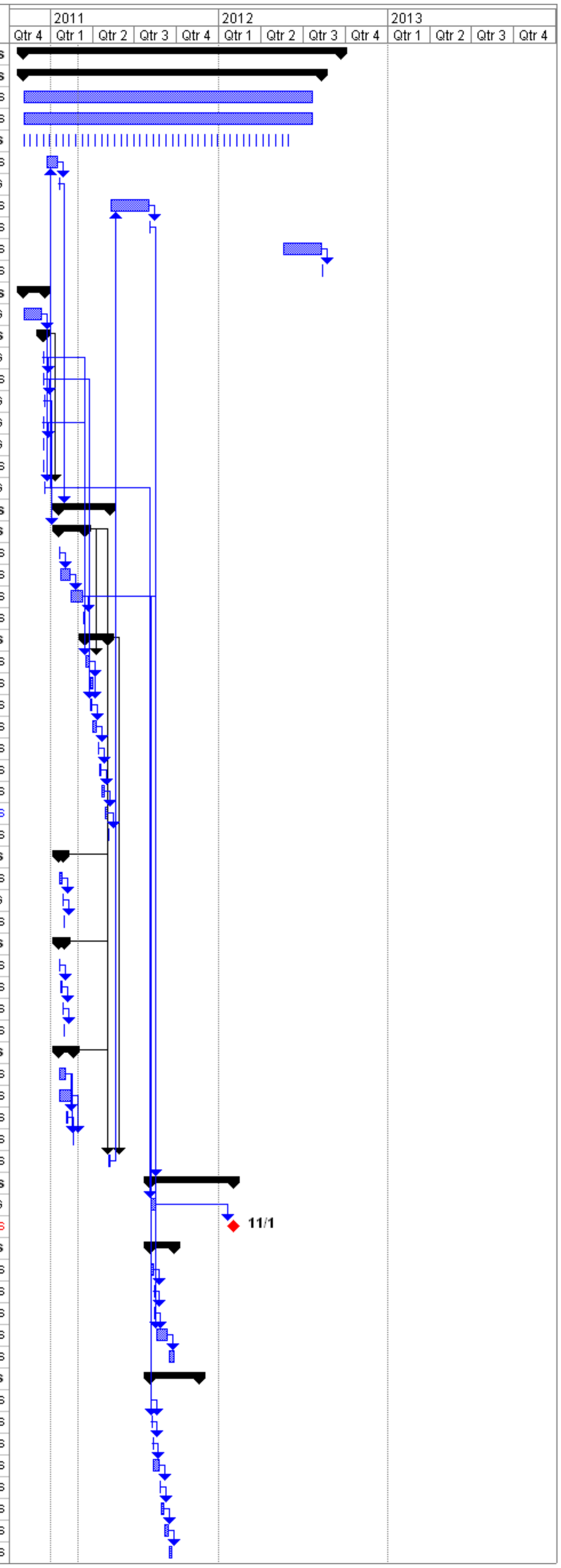


ID	WBS	Task Name	Work
40	1.4	**Opto-mechanics**	**890 hrs**
41	1.4.1	**Optical Design**	**260 hrs**
42	1.4.1.1	Plate scale trade study	40 hrs
43	1.4.1.2	Camera optics	100 hrs
44	1.4.1.3	Optics drawings for fab / get quotes	40 hrs
45	1.4.1.4	Telescope simulator	80 hrs
46	1.4.2	**Mechanical Design**	**372 hrs**
47	1.4.2.1	Pickoff	120 hrs
48	1.4.2.2	Field Lens	40 hrs
49	1.4.2.3	Dewar Interface / Focus Mechanism	112 hrs
50	1.4.2.4	Telescope simulator	100 hrs
51	1.4.3	**Fabrication, Assembly & Testing**	**258 hrs**
52	1.4.3.1	Pickoff	40 hrs
53	1.4.3.2	Field Lens	16 hrs
54	1.4.3.3	TT Mechanical Interface	30 hrs
55	1.4.3.4	Pupil Simulator	92 hrs
56	1.4.3.5	As-Built Documentation	80 hrs
57	1.5	**Controls**	**760 hrs**
58	1.5.1	**Motion Control**	**240 hrs**
59	1.5.1.1	Electronics Design	60 hrs
60	1.5.1.2	Software design	40 hrs
61	1.5.1.3	Software (PMAC, OBS, SC)	40 hrs
62	1.5.1.4	Software - DAR	20 hrs
63	1.5.1.5	Build cables	40 hrs
64	1.5.1.6	As-built Documentation	40 hrs
65	1.5.2	**Device Control**	**220 hrs**
66	1.5.2.1	Electronics Design	80 hrs
67	1.5.2.2	Camera control software design	30 hrs
68	1.5.2.3	Camera Control Software	30 hrs
69	1.5.2.4	Build cables	40 hrs
70	1.5.2.5	As-built Documentation	40 hrs
71	1.5.3	**Real-time Control**	**300 hrs**
72	1.5.3.1	RTC Software Design	80 hrs
73	1.5.3.2	RTC Software coding	80 hrs
74	1.5.3.3	RTC Modifications Contract	80 hrs
75	1.5.3.4	As-built Documentation	60 hrs

ID	WBS	Task Name	Work
76	**1.6**	**Operations Software**	**960 hrs**
77	1.6.1	Design	320 hrs
78	1.6.2	Setup & Calibration Tool Modifications	20 hrs
79	1.6.3	Acquisition Tool	120 hrs
80	1.6.4	Planning Tool Modifications	120 hrs
81	1.6.5	Observing Script Modifications	30 hrs
82	1.6.6	FITS Header Modifications	30 hrs
83	1.6.7	User Interface Modifications	80 hrs
84	1.6.8	As-built Documentation	80 hrs
85	1.6.9	Testing & Optimization with Summit Sy	160 hrs
86	**1.7**	**Integration, Test & Commissioning**	**2,030 hrs**
87	**1.7.1**	**Laboratory I&T**	**570 hrs**
88	**1.7.1.1**	**Lab System Setup**	**150 hrs**
89	1.7.1.1.1	RTC crate with WFS & STRAP	50 hrs
90	1.7.1.1.2	Motion Control	40 hrs
91	1.7.1.1.3	Camera	60 hrs
92	**1.7.1.2**	**Lab System I&T**	**420 hrs**
93	1.7.1.2.1	Motion Control	80 hrs
94	1.7.1.2.2	Camera Control	60 hrs
95	1.7.1.2.3	RTC with camera sim	40 hrs
96	1.7.1.2.4	RTC with Camera	80 hrs
97	1.7.1.2.5	RTC Full test	40 hrs
98	1.7.1.2.6	Optical Performance Testing	40 hrs
99	1.7.1.2.7	Documentation	80 hrs
100	**1.7.2**	**AO Facility Modifications**	**300 hrs**
101	1.7.2.1	Design power, cooling, mechanical interfac	100 hrs
102	1.7.2.2	Fabrication	40 hrs
103	1.7.2.3	Implement power, cooling, mechanical inter	80 hrs
104	1.7.2.4	Install motion control	40 hrs
105	1.7.2.5	Install electrical cables	40 hrs
106	**1.7.3**	**Telescope I&T**	**1,160 hrs**
107	**1.7.3.1**	**Installation**	**160 hrs**
108	1.7.3.1.1	Pickoff, field lens, dewar	50 hrs
109	1.7.3.1.2	Telescope Simulator	30 hrs
110	1.7.3.1.3	Motion control electronics/software	20 hrs
111	1.7.3.1.4	Camera electronics/software	30 hrs
112	1.7.3.1.5	RTC	30 hrs
113	1.7.3.2	Daytime Functionality & Scale Factor Testin	100 hrs
114	1.7.3.3	Daytime Closed Loop Testing & Optimizatior	80 hrs
115	1.7.3.4	On-sky Functionality & Closed Loop Testing	300 hrs
116	1.7.3.5	On-sky Performance Characterization	220 hrs
117	1.7.3.6	On-sky multiple tip/tilt optimization	200 hrs
118	1.7.3.7	System Performance Document	100 hrs
119	**1.8**	**Operations Handover**	**320 hrs**
120	1.8.1	Operations Documentation	160 hrs
121	1.8.2	Operations Training	160 hrs



ID	WBS	Task Name	Work
1	1.3	**NIR TT Sensor Camera**	**6,022.4 hrs**
2	1.3.1	**Project management, meetings & reviews**	**834 hrs**
3		Management and requirements control	180 hrs
4		Technical lead	360 hrs
5		**Team meetings**	**198 hrs**
48		**Schedule contingency, for SDR**	0 hrs
49		*System Design Review @ Caltech*	*0 hrs*
50		**Schedule contingency for DR**	0 hrs
51		Design Review @Caltech	48 hrs
52		**Schedule contingency for PSR**	0 hrs
53		Preship Review @Caltech	48 hrs
54	1.3.2	**Systems engineering**	**128 hrs**
55		*Refine functional perfromance requirements*	*60 hrs*
56		**Interface Control Documents**	**68 hrs**
57		*Space envelope*	*8 hrs*
58		AO bench interface	24 hrs
59		*Optical performance*	*8 hrs*
60		*Cooling system, compressor or He gas li*	*4 hrs*
61		*Electronics location, power, comms*	*8 hrs*
62		Data and command flow	16 hrs
63		*System Review Preparation*	*0 hrs*
64	1.3.3	**Design**	**1,012 hrs**
65		**Optics**	**328 hrs**
66		Window FEA	24 hrs
67		Design relay optics	120 hrs
68		Design optics mounts	160 hrs
69		Optics mount write up and PDR presntati	24 hrs
70		**Dewar**	**476 hrs**
71		Dewar layout & conceptual design	128 hrs
72		Design vacuum enclosure	56 hrs
73		Design interface to AO bench	24 hrs
74		Design detector mount	96 hrs
75		Design getter enclosure	20 hrs
76		Design cold baffles	48 hrs
77		Design radiation shields	40 hrs
78		Design filter wheel, drive and housing	40 hrs
79		Dewar design doc & PDR presentation	24 hrs
80		**Thermal control system**	**64 hrs**
81		Thermal modelling & design	40 hrs
82		*Cryocooler selection*	*8 hrs*
83		Thermal design document and PDR pres	16 hrs
84		**Electronics**	**72 hrs**
85		Design wiring inside dewar	24 hrs
86		Design cables from dewar to controller	16 hrs
87		Design wiring within controller	16 hrs
88		Electonics design write up and PDR pres	16 hrs
89		**Software**	**48 hrs**
90		Define DSP command and data flow, cod	0 hrs
91		Define detector host, command and data	0 hrs
92		Design temperature and pressure loggin	0 hrs
93		Software write up and PDR presentation	48 hrs
94		Design Review preparation	24 hrs
95	1.3.4	**Procurement and Fabrication**	**2,684.4 hrs**
96		*Detector purchase*	*0 hrs*
97		Detector delivery	0 hrs
98		**Optics**	**304 hrs**
99		Relay optics procurement	40 hrs
100		Pupil mask design & procurement	8 hrs
101		Filter procurement	16 hrs
102		Fabricate optics mounts	160 hrs
103		Install optics in mounts	80 hrs
104		**Dewar**	**592.4 hrs**
105		Procure vacuum gauge and controller	16 hrs
106		Procure other dewar parts: valve, press re	8 hrs
107		Procure hermetic connectors	2 hrs
108		Fabricate vacuum enclosure	80 hrs
109		Fabricate front flange and window frame	0 hrs
110		Fabricate radiation shields	48 hrs
111		Fabricate cold baffles	48 hrs
112		Fabricate getter enclosure	40 hrs



ID	WBS	Task Name	Work
113		Fabricate detector mount and hatches	80 hrs
114		Fabricate filter wheel, drive parts and hou	48 hrs
115		Assembly and fit check	48 hrs
116		Test filter drive warm	20 hrs
117		Clean, bake and reassemble	40 hrs
118		Install temperature sensors, heaters and	24 hrs
119		Fabricate wiring inside dewar and ohmic	8 hrs
120		Install and align optics warm	56 hrs
121		Check and fix leaks	12 hrs
122		Pump and bake dewar	2.4 hrs
123		Pressure rise tests	12 hrs
124		**Thermal control system**	**56 hrs**
125		*Crycooler purchase*	*4 hrs*
126		Lakeshore controller purchase	8 hrs
127		Purchase sensors and heaters	8 hrs
128		Fabricate cable form dewar to temp contr	20 hrs
129		Test sensors, heaters and servo while w	16 hrs
130		**Detector Electronics**	**242 hrs**
131		Procure circular connectors fro cables to	2 hrs
132		Procure D connectors within controller	4 hrs
133		**Procure 16ch IR Leach controller**	**8 hrs**
134		6 slot housing	8 hrs
135		Large power supply	0 hrs
136		PCI card	0 hrs
137		Timing board	0 hrs
138		IR Clock driver	0 hrs
139		8ch IR video board	0 hrs
140		8ch IR video board	0 hrs
141		Test leach controller	76 hrs
142		Fabricate and ohmic check cables from d	48 hrs
143		Fabricate and ohmic check wiring withing	80 hrs
144		End-to-end ohmic check from det mount t	8 hrs
145		Electrical check of signals in cable at dew	16 hrs
146		Purchase Linux server, rack mount	4 hrs
147		Purchase Terminal server, rack mount	4 hrs
148		Purchase Remote power switch	2 hrs
149		**Software development**	**1,480 hrs**
150		*DSP coding for detector readout and coa*	*240 hrs*
151		Software interface to temperature controll	80 hrs
152		*Interface Leach controller to AO system*	*480 hrs*
153		Operators manual	80 hrs
154		*Reliability testing / software contingency*	*600 hrs*
155	**1.3.5**	**System integration and test at Caltech**	**1,060 hrs**
156		**Vacuum and thermal tests**	**104 hrs**
157		Vacuum gauge and pressure logging vali	16 hrs
158		Assemble & test with cryocooler	16 hrs
159		Log temperature through 1st cooldown	16 hrs
160		Adjust thermal servo	8 hrs
161		Log temperature through 1st warm up	8 hrs
162		Tune thermal links	16 hrs
163		Pump, repeat thermal cycle, servo tuning	12 hrs
164		Pump, repeat thermal cycle, servo tuning	12 hrs
165		Test filter mechanism cold	20 hrs
166		**Detector testing**	**504 hrs**
167		Electrical check of signals at detector mo	8 hrs
168		Detector installation	16 hrs
169		Detector acceptance testing	240 hrs
170		Detector noise perfomance characterizati	240 hrs
171		Align & test optics cold	40 hrs
172		Communication test to AO controller simulato	32 hrs
173		Spot/pinhole centroiding tests in lab	120 hrs
174		Test reports (performance verification)	80 hrs
175		Maintenance procedures and diagnostics	80 hrs
176		*System integration contingency, no longer fur*	*0 hrs*
177		PreShip Review Preparation	80 hrs
178	**1.3.6**	**Commisioning support at Keck**	**304 hrs**
179		Pack ship shipping of hardware, incl insuranc	48 hrs
180		*Detector team lead, no longer funded*	*0 hrs*
181		Electrical engineer	128 hrs
182		*Detector system programmer, no longer fund*	*0 hrs*
183		Host layer programmer	128 hrs