The Cassegrain ADC for Keck I
Preliminary Design Review Report

November 4, 2003, Final Version

INTRODUCTION

The Technical Facilities group of the UCO/Lick Observatory located on the Santa Cruz campus of the University of California Santa Cruz (UCSC) is designing a Cassegrain Atmospheric Dispersion Corrector (ADC) for the Keck I telescope at the W.M. Keck Observatory (WMKO).

This is the report of the preliminary design review (PDR) committee, resulting from the PDR meeting, which was held at UCSC on October 15, 2003.

COMMITTEE MEMBERS

The PDR committee members were:

Keith Taylor, Caltech – Chairman
Jacques Beckers, University of Chicago
Jacques Sebag, NOAO
Hien Tran, WMKO
Sergey Pantleev, WMKO

This is the final version of the PDR report. It has been written by Sean Adkins (Instrument Program Manager, WMKO) and reviewed by the committee and the committee chair, Keith Taylor.

The PDR meeting was attended by all members of the committee except for Jacques Beckers who reviewed the preliminary design report and provided comments prior to the meeting. In addition the meeting was attended by various members of the UCO/Lick and WMKO staff.

SUMMARY

The outcome of the PDR may be summarized as follows:

1. The review committee recommends that the Cassegrain ADC proceed to completion. The committee commends the ADC design team for an excellent job in the preliminary design phase and thanks them for the completeness of the PDR documents.

2. Cost to completion estimates finalized after the PDR meeting indicate an increase of $144K in the total cost of the project. While the committee realizes that any cost increase places additional pressure on a very tight observatory budget, the committee was of the opinion that cost growth of this magnitude is not unreasonable given the state of the design at the delta conceptual design review and the design refinements made during the preliminary design phase.

3. Specific issues have been raised that need to be addressed during the detail design phase, but none of these are issues that should impede the continued development of the ADC or its successful completion and satisfactory operation.

CHARTER

The objective of preliminary design is to establish the feasibility and performance of the design proposed for the instrument. This design will be completed in the next phase of the project, the detail design phase. The preliminary design work for the Cassegrain ADC includes a complete optical design so that optical procurement and fabrication can start at the beginning of the detail design phase.

The charter for the review committee was established in the document "*The Cassegrain ADC for Keck I Preliminary Design Review Process and Charter*" dated September 16, 2003 and revised September 24, 2003.

The objective of the PDR is to evaluate the work done in the preliminary design phase, and to consider the preliminary specifications and their suitability to the scientific goals of the instrument and the requirements of the observatory. The PDR will also examine the schedule and budget proposed for completion of the instrument.

DISCUSSION

The first part of the meeting consisted of an overview of the instrument combined with discussion of various details, and was convened with the following groups in attendance: the PDR committee, the Cassegrain ADC design team at Lick, the WMKO staff participating in the Cassegrain ADC project, and members of WMKO management.

The second part of the meeting was an executive session of the PDR committee.

During the meeting attention was focused on specific areas. The discussions and recommendations for each area are summarized in the following sections.

Science Gain from the ADC

The committee expressed some concern that a quantitative assessment of science gains from the ADC has not been attempted. Given the scope and importance of the project, it is thought that an additional assessment of the gains from the ADC should be made. In particular the science gains should be quantified in "typical" configurations detailing the performance of LRIS without the ADC; LRIS with a perfect ADC; and LRIS with the predicted performance of the ADC as designed in order to define weights to the various design decisions being made.

Impact of Focus Shift and Plate Scale Changes

The ADC introduces a focus shift that increases with zenith angle as the prisms separate. The total focus shift amounts to about 8 mm of displacement in the focal surface, and this must be compensated for by refocusing the telescope using the secondary mirror. Refocusing causes a change in plate scale due to the change in telescope focal length. This introduces an error of about 0.33" (center to edge over the LRIS field of view), which must be taken into account when designing a slit mask. The ADC design team has considered this issue and the project plan includes the small amount of work required to modify the slit mask design software written by UCO/Lick.

Mechanical Design Comments

Finite element analysis was used to verify the rigidity of the proposed design, and most of the critical factors have been taken into account. Concern was expressed about two issues, alignment of the mechanical and optical components at assembly, and the loading of the lead screws used to drive the two prisms.

A general plan for alignment has been developed, and the mechanical tolerance requirements established by the optical design are all achievable with normal fabrication and assembly practices.

- **The committee recommends that a detailed assembly and alignment procedure be developed during the detail design phase.**

Gravity acting on the prism cells as the telescope elevation changes will cause the prism cells to place a moment on the lead screw via the nut. The deflection produced is minimal as the lead screws are 25 mm in diameter. Cyclic loading due to the deflection is well below the endurance limit and the estimated life of the nut and bearing is not impacted. The end of each lead screw is turned down to a shaft, which passes through two bearings, so eccentric motion of the shaft end is not expected, but this will be reviewed in the detail design phase.

Optical Performance

The committee asked why 60 degrees zenith angle was chosen as the design limit for correction. It was explained that the exposure time increase from 60 to 72 degrees is not very great, while at the same time the extinction of the shorter wavelengths is very high, reducing the likelihood that observations made at zenith angles greater than 60 degrees would require the benefits of the ADC.

The 2.5 degree prism angle was chosen as the best compromise between the weight of the prisms and the amount of separation required for full correction at 60 degrees. Thinner prisms would produce a negligible improvement in image quality and would also result in a very long ADC that would be difficult to make rigid.

The effects of refractive index inhomogeneity, thermal and mechanical stresses in the prisms were considered and the effects of all of these are insignificant. Grade D fused silica has been selected, and the refractive index variations in this grade of glass are still well below what is required for the ADC. A lower grade of glass was not considered due to the potential for an increase in other types of flaws.

- **Stress induced birefringence may have an impact on precision polarimetry, Jacques Beckers recommends that the ADC design team contact Keller at the National Solar Observatory for comments on this issue. Christoph Keller is evaluating these effects for the LADC design for the LBT. In lieu of other information the best recommendation is that the ADC not be used when precision polarimetric observations are done with LRIS.**

There was general agreement that the atmospheric dispersion values are well established by theory, and Drew Phillips reported that the estimates of ADC performance have been determined using two different modeling approaches and also appear to agree with the values given in earlier reports by Nelson and Mast.

The LRIS guider will see the same offset effects due to the ADC that are seen in the LRIS science field, so these effects will be corrected automatically in closed loop guiding. However, there are effects on pointing and it was confirmed that changes to the pointing model to account for this are included in the CARA portion of the software work for the ADC.

Performance evaluation for the ADC is included in the project plan, and it was noted by the committee that this should include representative spectra that can be used to quantify the scientific benefits of the ADC at commissioning.

Coatings

- **It is the opinion of the committee that additional attention needs to be given to characterizing the coatings and confirming the transmission that will be achieved.**

The decision to proceed with the full aperture ADC was based on the understanding that transmission would be high enough (and optical performance impact at null small enough) that the ADC could be left in place for much of the LRIS observing program (and certainly for an entire observing night).

There was also concern about the durability of the coatings, particularly dust collection on the top prism surface when the telescope is pointed at the zenith. In addition the possibility of condensation exists, and the effect of this on the Sol-gel coating is not known to a high degree of certainty by anyone on the design team or the committee. It was also noted that non-contact cleaning with CO_2 snow is commonly used for optics cleaning at the observatory and the compatibility of this with Sol-gel is unknown.

Further concern exists about any possible aging effects causing a reduction in coating transmission, particularly at the shorter wavelengths. The upcoming HIRES CCD Upgrade was identified as an opportunity to evaluate a Sol-gel coating in this regard (albeit one that has spent most of its life in the dark) since the field flattener of the existing dewar has a Sol-gel coating and the transmission was measured when it was fabricated about 10 years ago.

- **The committee recommends that this field flattener be removed after the upgrade is complete and sent to Livermore for measurement of transmission. The original and new transmission curves can then be compared to look for aging effects. The committee also recommends that other groups be contacted for information about coating durability and aging effects.**

- **The committee recommends that test coatings be done to confirm the transmission and to evaluate compatibility with various cleaning procedures. It was noted that a part of the observatory requirements for the ADC is the development and documentation of a cleaning procedure and it is also a requirement that the prism mountings be compatible with the solvent(s) used in cleaning.**

Software

It is noted that the software changes to the pointing model and the requirement for focus adjustments are taken into account in the CARA software work estimate for the ADC project.

- **The committee recommends that the effect of the ADC be evaluated in terms of the acceptable tolerances for pointing and focusing accuracy. In addition a procedure should be designed for the commissioning process to verify the pointing and focusing performance with the ADC and compare it to performance without the ADC.**

- **It is also recommended that any GUI designs required should be defined in the detail design phase.**

- **The committee also comments that based on experience with other ADCs, the ideal situation is an ADC that is transparent to the user. Some expert observers may derive benefits from having control of the ADC but these will be minor compared to the significant reduction in ADC performance that can result from not having a complete understanding of the operation of the ADC.**

Schedule and Budget

There has been a 14% increase in the total cost of the project. At the delta conceptual design review the total cost was projected to be \$1.04M, and it is now projected to be \$1.19M. The increase can be attributed in large part to changes made as the design evolved and errors in estimating. There has also been a cost impact from the observatory requirements. The changes to the UCO/Lick portion of the budget are summarized in table 1.

Cost Category	**Amount of Increase**	**Explanation**
Electronics	$34,000	The requirements document requests conformance to the National Electric Code and UL 508, this requires time for Lick staff to study the standards and make any needed changes to existing work practices.
	$13,000	At conceptual design the cost estimate was based on previous projects, now done to a schematic and parts list at today's prices. A standard 30% markup to parts costs for shipping, tax, and handling costs was also left out at conceptual design
Mechanical	$22,500	This is due to changes in the mechanical design since the delta conceptual design estimate, and the standard 30% markup to parts was omitted from the budget at conceptual design.
Software	$10,920	The cost calculations done at conceptual design appear to have been in error, perhaps due to different assumptions about personnel.
Assembly and Test	$26,175	Testing scope has increased since the conceptual design; the estimate now includes testing at a range of angles. (The testing estimate presented at the PDR was $48,400 which included testing at 0 °C, this portion has been eliminated as there is little likelihood of differential contraction problems since the mechanism is all steel.)
Shipping	$9,750	Shipping containers will require some engineering labor, ADC will ship fully assembled.
Total Increase	**$116,345**	

Table 1: Summary of Budget Changes

Considerable discussion took place on the subject of the budget and schedule, and concern was expressed that the schedule may lack detail, increasing the risk. However, the project is also fairly simple, so it is not clear that re-planning is required. It was also pointed out that the plan assumes dedicated Lick staff availability of 70%, and this is normally available to the project.

- **Because of the cost increase, the contingency was discussed and the committee recommended that the amount of contingency be reviewed in the areas where risk has been reduced by the preliminary design work, and where firm costs are known.**

Dave Cowley, the ADC project manager for UCO/Lick has made the requested contingency review, and the result is a reduced contingency based on the analysis given in table 2.

Contingency Applied to	Conceptual Design Amount	Reduction	Rationale for reduction
Optical materials	$36,577	$20,177	Subcontractors will supply optical materials and fabrication on a fixed cost basis. An amount will be retained cover possible sales taxes (an exemption will be applied for).
Mechanical Engineering	$8,320	$4,230	PD phase completed.
Mechanical Fabrication	$8,284	$1,784	Actual parts quotes in hand.
Reviews	$12,840	$6,840	PDR completed.
Total Reduction		**$33,031**	

Table 2: Contingency Revisions

The original contingency amount for the UCO/Lick portion of this project was $169,014. $6000 of this amount has been spent to cover the additional work to model the performance of the ADC with LRIS, as recommended by the delta conceptual design review committee. $2000 has been spent due to the need to correct a previously created Zemax model of LRIS that was supplied to UCO/Lick. The remaining contingency is therefore $161,014. With the reductions listed in table 2 the contingency amount is now revised downward to $127,983 for the remainder of the project.

The ADC project manager has suggested that an additional savings of approximately $20K could be realized if the detail design review was skipped and the drawings and fabrication plans were simply reviewed informally by WMKO staff. This suggestion was made after the PDR meeting so the committee is not in a position to comment on the appropriateness of this suggestion.

The observatory estimates for the costs involved in implementing the interface for the ADC have also increased by $69K. This increase results from an increase in the mechanical design and implementation effort for the mounting of the ADC in the tertiary tower, and an increase in the effort to implement local control of the defining points for the ADC. It is also important to note that due to the observatory's fixed person power and labor budget this increase simply forces a re-prioritization of work, it does not cause any actual increase in the observatory's budget.

While the committee realizes that any cost increase places additional pressure on a very tight observatory budget, the committee was of the opinion that cost growth of this magnitude is not unreasonable given the state of the design at the delta conceptual design review and the design refinements made during the preliminary design phase.

Questions from the Charter

The review committee was asked to answer 7 specific questions given in the PDR charter. The questions and answers follow.

1. Does the preliminary design report provide an appropriate set of science requirements for the Cassegrain ADC in view of the capabilities of the LRIS instrument on the Keck I telescope and the science cases proposed to justify the implementation of the Cassegrain ADC?

Answer: Yes, with the caveat that the science gains should be established in quantitative terms in order to guide design decisions and priorities.

2. Does the projected performance of the Cassegrain ADC described in the preliminary design report and in the preliminary specifications meet the science requirements?

Answer: Yes, the performance of the ADC as designed has minimal impact on LRIS image quality and provides the expected benefits of dispersion correction over the desired range of zenith angles and wavelengths.

3. Do the preliminary specifications for the Cassegrain ADC meet the observatory requirements?

Answer: Yes, the compliance matrix provided as part of the PDR documents indicates a good understanding of the requirements and the preliminary design is compatible with these requirements in all areas essential to the performance and usability of the ADC.

4. Is the optical design presented in the preliminary design report ready to be released for fabrication?

Answer: Yes, the committee commends the work of the team (and Drew Phillips in particular) for a good design with a complete and well-presented analysis. Since coating is the final step there is time to perform the testing requested by the committee during the detail design phase prior to the time when the optics will be ready for coating.

5. Does the proposed design present any features that raise concern for maintainability and reliability?

Answer: Yes, in two areas. First, the design should address the possibility of dust ingress to the second prism upper surface when the telescope is at zenith with the ADC installed. An effort should be made to minimize the paths for dust to reach that second prism surface. Second, the durability and aging characteristics of the Sol-gel coating should be investigated and discussed with the observatory along with cleaning procedures and requirements.

6. What is the likelihood of success in performance, schedule and budget terms?

Answer: The committee feels that success is likely. There are some reservations about the level of schedule detail and the risk this may represent. For this reason the committee recommends that an additional reserve of $50K be allowed to cover any unforeseen cost increase at the detail design review, making the total budget $1.24M.

7. Are there any other risks that should be considered in the continuation of the development plan?

Answer: Yes, the risks related to the coatings have been highlighted, as well as concerns about the schedule.

CONCLUSIONS

The review committee recommends that the Cassegrain ADC proceed to completion. The committee commends the ADC design team for an excellent job in the preliminary design phase and thanks them for the completeness of the PDR documents.

The committee also recommends that a final total for the project including the contingency be set at $1.24M.

The following specific points should be addressed in the detail design phase activities:

1. The ADC science gains should be quantified in "typical" configurations detailing the performance of LRIS without the ADC; LRIS with a perfect ADC; and LRIS with the predicted performance of the ADC as designed.

2. A detailed assembly and alignment procedure for the ADC should be developed during the detail design phase.

3. The performance evaluation of the ADC at commissioning should include representative spectra taken with and without the ADC that can then be used to further quantify the scientific benefits of the ADC.

4. Additional attention should be given to characterizing the coatings and confirming the transmission that will be achieved. In particular test coatings should be done to confirm the transmission and to evaluate compatibility with various cleaning procedures.

5. The field flattener from the original HIRES dewar should be removed after the upgrade is complete and sent to Livermore for measurement of transmission. The original and new transmission curves can then be compared to look for aging effects. Other groups should also be contacted for information about coating durability and aging effects.

6. The effect of the ADC should be evaluated in terms of the acceptable tolerances for pointing and focusing accuracy. In addition a procedure should be designed for the commissioning process to verify the pointing and focusing performance with the ADC and compare it to performance without the ADC.

7. Any software GUI designs required by the ADC should be defined in the detail design phase.

APPENDICES

Budget Comparison

Table 3 on the next page is a comparison of the budgeted costs at the delta conceptual design review and new cost estimates finalized after the preliminary design review.

Expenses	Notes	FY03	FY03	FY04	FY04	FY04 Original Estimates	FY04 Original Estimates	FY05	FY05	FY05 Original Estimates	FY05 Original Estimates	Project Totals	Delta CoD Original Estimates	Difference	
Labor		FTE													
ME		0.19	$ 19,850	0.51	$ 53,281	0.19	$ 19,850	0.10	$ 10,447	0.18	$ 18,805	$ 83,578	$ 58,505		
MT			$ -	0.08	$ 5,800	0.11	$ 7,975	0.19	$ 13,774		$ -	$ 19,574	$ 7,975		
MD			$ -	0.13	$ 9,425		$ -		$ -		$ -	$ 9,425	$ -		
EE		0.02	$ 2,089	0.30	$ 31,342	0.11	$ 11,492	0.08	$ 8,358		$ -	$ 41,789	$ 13,581		
ET			$ -		$ -		$ -		$ -		$ -	$ -	$ -		
SE			$ -	0.10	$ 10,447	0.10	$ 10,447	0.05	$ 5,224	0.05	$ 5,224	$ 15,671	$ 15,671		
IE			$ -	0.02	$ 2,089	0.06	$ 6,268	0.04	$ 4,179	0.08	$ 8,358	$ 6,268	$ 14,626		
IT			$ -		$ -		$ -	0.04	$ 2,900		$ -	$ 2,900	$ -		
SA		0.02	$ 2,089	0.10	$ 10,447	0.10	$ 10,447	0.05	$ 5,224	0.05	$ 5,224	$ 17,760	$ 17,760		
OA			$ -		$ -		$ -		$ -		$ -	$ -	$ -		
IPM		0.10	$ 10,447	0.10	$ 10,447	0.10	$ 10,447	0.02	$ 2,089	0.02	$ 2,089	$ 22,984	$ 22,984		
Total Labor	1	0.33	$ 34,476	1.34	$ 133,278	0.77	$ 76,927	0.57	$ 52,195	0.38	$ 39,700	$ 219,949	$ 167,330	$ 52,619	31%
Materials															
Mechanical					$ 10,000		$ 10,000					$ 10,000	$ 10,000		
Electrical					$ 5,000		$ 5,000					$ 5,000	$ 5,000		
Data Processing															
Computers												$ -			
Data Storage												$ -			
Software												$ -			
Misc.	2				$ 9,000		$ 5,000					$ 9,000	$ 5,000		
Total Materials			$ -		$ 24,000		$ 20,000		$ -		$ -	$ 24,000	$ 20,000	$ 4,000	
Subcontracts	3,4,5		$ 51,230		$ 259,447		$ 687,803		$ 544,701			$ 804,148	$ 687,803	$ 116,345	17%
Travel	6				$ 8,000				$ 4,000			$ 12,000	$ -	$ 12,000	
Contingency	7				$ 8,000							$ 127,983	$ 169,014	$ (41,031)	
Project Total			$ 85,706		$ 432,725		$ 784,730		$ 600,896		$ 39,700	$ 1,188,080	$ 1,044,147	$ 143,933	14%

Notes (these apply to the current estimate items unless noted otherwise):
1. **Note to FY03 labor cost column**: the actual ME labor for FY03 is less than estimated at the delta conceptual design review by $16,228, and for comparison purposes $16,228 has been added to the total labor amount in the Delta CoD Original Estimates column.
2. This amount is for consulting on the addition of defining points and instrument load to the Keck I mirror tower ($5000) and $4000 for a machinist subcontract to modify the LRIS hatch
3. Subcontract to UCO/Lick Technical Facilities Group
4. The FY03 amount consists of $51,230 from the conceptual design phase that has been expended but not yet invoiced by UCO/Lick
5. Travel is for PDR and DDR in FY04, and PSR in FY05
6. $8000 of contigency has been spent in the PDR phase, $6000 for the optical analysis including LRIS recommended by the CoDR review, and $2000 of extra work to fix the Zemax models of LRIS that we not working correctly (supplied by CARA, done several years back).
7. 25% of the cost to completion (total is $726,268) is shown in FY04, and the balance shown in FY05

Table 3: Budget Comparison

Questions and Comments Submitted in Advance by Committee Members

(Comments or questions are in *italics*, responses by the ADC design team in normal type.)

Jacques Sebag:

1 Coating

On which sides are the coatings? All 4 prism surfaces.
How is the alignment tab glued to the prism? With the same materials used for the DEIMOS tent mirror. This will be specified in detail design.

What it the durability of the sol-gel coatings? We have them on an ADC on the Shane telescope. They have been there several years and have been cleaned successfully.

2 Mechanisms

Is there a brake on the ADC? No, we do not believe that one is needed.

Is there a "skew sensor" on the ball bearings? No, we do not believe that one is needed.

I am not sure I understand the linear speed calculation? Is it variable? How is the speed controlled? The speed required for tracking is not constant. It is controlled with a DC servo motor driving the ball screw through a gear box and timing belt. The ball screw has a pitch of 0.2" per revolution. The timing belt ratio is 1:1. The gearbox ratio will be 8:1 or 10:1. The speed is controlled from an encoder on the motor that has 4000 counts per revolution and checked in software be an encoder on the ball screw.

Do you lose alignment if the belt breaks? No. We will loose track of position and need to re-home the linear stage.

3 Optics

Residual dispersion: Zemax was used for these calculations. How does that compare to Nelson's model? Checked with other software as well, that model included a wide range of supplemental parameters. Quick review of Nelson report shows similar dispersion values to those determined by both Zemax and other software.

Do you have measurements with LRIS to compare to the models? LRIS performance was analyzed with and without the ADC using Zemax. Test spectra with and without ADC will be taken as part of the performance evaluation for the ADC that is included in the project plan

Image quality: were the deformations from the FEA analysis used in the image quality estimation?

FEA deformations not used in image quality evaluation – did look at effect of deformation (if present) on optical quality. Order of magnitude larger than found in FEA caused ray deviations of only 7 microns. About 1 micron deviation seen, compare this to 100 micron image size.

4 Alignment

I don't understand how the translation mechanism is set and kept parallel to the optical axis. What is the reference? The prisms and the stage will be aligned in the instrument during fabrication and assembly. This will set the prisms to the proper angles with each other and in the proper positions relative to the translation axis. The instrument will then be aligned to the telescope by shimming the defining points during commissioning. Cross hairs will be supplied on the prism cells to align to in the telescope. Reference flats will be provided on the cells to check angles during commissioning.

What is the clocking position of the ADC relative to the elevation axis? The forward prism is base up and the aft prism base down relative to the horizon.

5 Environment

Covers: when are the covers removed? Are they reinstalled at the beginning of the day? Would they protect from condensation? How is the whole mechanism sensitive to dust? The covers will be removed when the ADC is installed on the telescope and replaced when it is removed from the telescope. They will protect when the instrument is stored on the Nasmyth deck only. The mechanisms have shields to protect from dust.

6 Others

What are the maintenance issues? Lubrication and cleanliness of ball slides and ball screws. Cleanliness of the optics.

Jacques Beckers:

1. *In section 3.1 (science justification) the text is missing.*

2. *I do not know by how much the air density/pressure changes on Mauna Kea, but it may be enough to require it to include in the control of the ADC since the amount of atmospheric dispersion then changes.*

3. *I suspect that polarization effects are not an issue in the use of the ADC. But just in case: Christoph Keller at NSO is looking into this in connection with the LBT. One may want to contact him (ckeller@nso.edu).*