HIRES CCD UPGRADE

for

The Keck 1 Telescope, Mauna Kea, Hawaii

Project Plan

Engineering Services
UCO/Lick Observatory
Santa Cruz, California

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1 Introduction

The purpose of this project is to upgrade the HIRES detector, dewar, and CCD electronics. The existing CCD is a 2k x 2k Textronix device with 24 micron pixels. The newsystem will consist of a mosaic of three 2k x 4k MIT/Lincoln Labs CCDs. These devices have 15 micron pixels and significantly improved response shortward of 380 nm compared to the current CCD. The goals are to

1. improve the blue/UV response (factor of 2 at 350nm)
2. increase the single-setting wavelength coverage
3. decrease the readout time (<30 seconds/readout)
4. reduce the readout noise (<3 e-/read).

The challenge to accommodate the larger geometry will extend to several levels. Mechanical packaging needs to be modified for the new mosaic and to handle the higher heating loads and cooling requirements. A new optical field flattener will be needed to accommodate the flat focal plane characteristics of the new mosaic and to fit with the new structure. Electronic requirements are now scaled by three and will drive packaging and complicate wiring, routing, connections, and feedthrus. Software must also be enhanced and upgraded to work with the new electronics and the higher image density.

2 Work Scope

2.1 CCD’s

2.1.1 Testing

The candidate CCDs will be tested and evaluated. Operating constraints (like maximum operating temperature) will be identified and optimized operating parameters will be determined. Performance (quantum efficiency, charge transfer efficiency, etc.) will be measured.

2.1.2 Metrology

Making a coplanar array of CCD’s is a challenge. To put the three CCD’s in a coplanar mosaic requires very careful metrology of the CCD’s. Custom CCD "feet" must be fabricated and tested with additional metrology.

2.1.3 Mosaic assembly

The CCD’s must be assembled on a mosaic backplane. This requires precise alignment of the CCD’s and further metrology after the CCD’s are mounted.

2.2 Mechanical

2.2.1 Dewar

The dewar will grow in size to accommodate the larger mosaic. This requirement helps with the connector arrangement on the rear lid which provides electronic feedthrus to the pre-amplifier electronics. The existing 41 pin connector will be replaced with three miniature 51 pin DSUB connectors and 6 SMA connectors. At its other end, a new field flattener will be accommodated. The CCD support structure and back plate assembly will be patterned after DEIMOS. A getter will be added which will use zeolite as the absorber.

2.2.2 Electronic Packaging

The pre-amplifier housing, which attaches to the dewar, will be redesigned to accept the new and additional board it will contain. Access to boards and test points are critical, as well as shielding between the PCB's. New connector feedthrus from PAVE are being proposed and show great promise of improvement. Since they are not rated to our vacuum levels they will be tested to insure that they meet these requirements.

2.2.3 Cooling

Multiple CCD's and more electronics will result in a higher heat load. Care must be taken to ensure that the mosaic is maintained at its proper temperature. LN2 will continue to be used as the cooling method.

2.2.4 Miscellaneous

The spider support structure holding the dewar in place will be modified for the larger dewar housing. Routing of cables and wiring within shadows will be a bigger challenge because there will be more of them. Other items include such things as testing, fixturing, and preparation for shipping.

2.3 Optics

A new field flattener window will be needed for two reasons. One is due to the increased size of the mosaic. The other is due to the flat focal plane characteristics of the new CCD's from Lincoln Labs. We already have in house an existing fused silica blank for the part. An AR coating is required and will be done at LLNL.

2.4 Electronics

2.4.1 CCD Controller

The 1x3 CCD mosaic will require a more populated controller.

A. The CCD controller will be built as a SDSU-2 controller rather than the SDSU-1 of the existing system. This new controller chassis will be different than the original chassis.

B. An upgrade is desired for the Power Monitor board for better control and diagnostics for the system.

C. There is also a preference to upgrade and re-layout the Utility Support board for better control of the shutter controller.

2.4.2 Electronics Box

New SDSU-2 dewar boards and cabling sets will be required. Design and layout of PCB's will need special consideration to space and configuration. A new power filter board for the three CCD's will also be needed along with a preamp and analog switch boards; a set for each CCD.

2.4.3 VME Crate

A new off-the-shelf product of different size will be used for the new chassis. The Sparc-1E CPU board will be replaced with a Motorola MVME2304 board. Existing memory will be replaced with a 256K memory board.

2.4.4 Dewar

Cable sets and PCB's (for each CCD) need to be designed and built. Stuffing more components into the dewar will be a challenge

2.4.5 Miscellaneous

New hermetic feedthrus from Pave Technology are being considered. They are only rated to 10^{-6} Torr. But if they can meet our vacuum requirements, they will greatly simplify and minimize the penetration footprint in the dewar lid. Getting the wiring thru this interface may be the driver on the dewar size. These Pave connectors will significantly minimize this risk.

2.5 Software

2.5.1 CCD Controller

Both the timing board DSP and utility board software will be replaced with second generation upgrades.

2.5.2 VME Crate

The VMEINF board DSP software will be replaced with a second generation upgrade. Motorola architecture S/W will replace the existing Sparc architecture VME S/W. And the single CCD temperature servo loop will be replaced with a multi CCD version instead.

2.5.2 Host Computer

Lickserv-1 will be replaced with lickserv-2 to permit mosaic readouts. DS9 will replace FIGDISP. New configuration files will be developed for the echelle simulator to map the mosaic. The "xpose" user interface will be updated or replaced for mosaic windows and binning.

3 Specifications

3.1 CCD

Item	Value	Units	Comments
AR Coating	2	UV/Blue	LLNL
	1	Real Teal	
Array size	2K x 4K	-	2048 x 4096
CCD Spectral range	3K–10K	Angstrom	
CTE	.999997	%/100	minimum
Dark current	2	e^-/hr/pxl	@ -130 °C
Operating temp	-130	°C	

Item	**Value**	**Units**	**Comments**	
Pixel size	15	μm		
Quantum efficiency	75	%	3000 Angstrom	MIT UV/blue
	75		6000	
	90		9000	RealTeal
	30		10000	RealTeal

3.2 Mechanical

Item	Value	Units	Comments
CCD alignment	---	---	X & Y; Best effort
CCD flatness	10	μm	Max., CCD plane z total flatness
CCD gap	50	μm	Max., Gap between CCD's; best effort
CCD rotation	.05°	degrees	Max., Best effort
CCD temperature	-130	°C	Operating temp at Keck
Ion Pump	---	---	Varian, Model #919-0520, 2 liter/sec mini CFF
LN2 hold time	24	hours	minimum
Mosaic flatness	10	μm	Peak-peak
Mosaic roll adjustment	±.75	degrees	Set at alignment

3.3 Optical

Item	Value	Units	Comments
Annulus flat	-	-	Dewar side; edge to CA
AR Coating			LLNL; details TBD
CA - concave	152	mm	
CA - convex	174	mm	
Material	-	-	Fused silica 7980, Grade 1B
OD	178	mm	
Radius, concave	948.192	mm	
Radius, convex	184.902	mm	
Thickness	48.041	mm	

3.4 Electrical/Electronics

Item	Value	Units	Comments
CCD flex circuit	Type	-	Straight (Right angle desired)
CCD flex circuit length	5	in	

Electronics box power comsumption	6	watts	2 watts/CCD

3.5 Software

Item	Value	Units	Comments

4 Technical challenges

The three CCD mosaic is forcing the dewar to grow in size and to increase the number of electronic components and PCB's in the system. Those within the dewar and the electronics box will also be increasing the heat load. Adequate and efficient cooling will be required.

Electronics also shares the packaging challenge. There will be more boards, wiring, and cabling. More power dissipated in heat to deal with. Another concern is getting viable connector feedthrus that also do not have any out gassing problems associated with them.

Several concerns relate to the CCD's themselves. Will residual image be an issue and what should be done about it if it is. Anti-blooming clocks should be sufficient to avoid any charge bleeding problems for existing calibration schemes. And sufficiently low dard current should also be achievable.

5 Project team

5.1 Barry Alcott, Electronics Lab Supervisor, 831-459-5509, *barry@ucolick.org*

- Develop CCD Controller
- chassis layout
- controller
  - EL-3193 Utility Support board mods & upgrades, artwork
  - build controller
    - modular power supply
    - build dewar electronics box
  - cabling
  - testing and troubleshooting
- Dewar shutter

5.2 Jerry Cabak, Senior Development Engineer, 831-459-5892, *cabak@ucolick.org*

- mechanical design & packaging
- Dewar
  - CCD Mosaic support structure
  - dewar housing
  - cold finger
- cooling – LN2
- Dark slide design modification
- electronic equipment housing & enclosures, feedthrus, fittings
- testing
- mechanical part documentation and drawings
- shipping

5.3 Marlene Couture, Projects Analyst, 831-459-3293, *mc@ucolick.org*

- Budget tracking and reports
- labor statistics
- Expense billing to CARA

5.4 Dave Cowley, Technical Facilities Manger, 831-459-2475, *cowley@ucolick.org*

- Project manager, budget & task management, meeting coordinator

5.5 Kirk Gilmore, Specialist, 831-459-3184, *gilmore@ucolick.org*

- CCD metrology
- Mosaic assembly

5.6 Grant Hill, Support Astronomer, 808-881-3865, *ghill@keck.hawaii.edu*

- Keck liaison
- CARA requirements

5.7 Dave Hilyard, Optician – Lick Optic Lab, 831-459-3269, *hilyard@ucolick.org*

- Field flattener / Dewar window
  - fabrication
  - testing
  - material procurement

5.8 Bob Kibrick, Director of Scientific Computing, 831-459-2262, *kibrick@ucolick.org*

- Supervise S/W development and testing effort
- Primary responsibility for new S/W for CCD controller and VME crate
- Supervise and coordinate testing of new host S/W with Steve Allen

- Conduct integration and testing H/W & S/W for
    - CCD controller
    - CCD VME crate
- Coordinate test and characterization of assembled CCD system in Santa Cruz
- Assist with installation and commissioning in Hawaii
- Primary responsibility for tests of remote operation from Waimea (& California)

5.9 Jeff Lewis, Instrument Laboratory Supervisor, 831-459-2112 *jeff@ucolick.org*

- Mechanical and component design & construction consulting
    - dewar
    - vacuum design
    - cooling
- Component & test fixturing fabrication
- System assembly, alignment, and test

5.10 Terry Pfister, Mechanician, 831-459-2624, *lois@ucolick.org*

- Dewar and vacuum component design assistance
- Vacuum components construction
- Vacuum system assembly and testing

5.11 Richard Stover, Detector Development Lab, 831-459-2139, *richard@ucolick.org*

- Testing & characterization of the Lincoln Lab CCD's

5.12 Steve Vogt, Professor/Astronomer, 831-459-2151, *vogt@ucolick.org*

- Principal Investigator & science consultant
- "QA administrator"
- Science requirements/user interface and systems integration

5.13 Mingzhi Wei, Assistant Research Astronomer, 831-459-4911, *wmz@ucolick.org*

- CCD testing

5.14 Chris Wright, Senior Design Engineer, 831-459-2835, *cwright@ucolick.org*

- Design & layout PCB's and associated hermetic connectors, cabling, and circuit board connectors.
- Dewar electronic box
- re-design/re-layout PCB's
- circuit board connection harnesses

- new cabling system from CCD controller to electronics box
- test & characterize electronics H/W at
- CCD controller
- electronics box
- dewar
- Assist in test and characterization of assembled system in Santa Cruz

6 Decision matrix

In most cases a decision matrix is used to clearly establish who will approve and who will be consulted and those that need to be informed of the significant and various aspects that change during the course of a project. It is especially useful when more than one group or department is involved.

Such is not the case here and it seems that a matrix is not needed at this time. The frequent and thorough project meetings characteristic at Lick involve all the participants who work well together and in a close knit and constructive environment. Steve Vogt and Dave Cowley will share approval power over budget, work scope, and schedule. All technical issues and details will be covered in the meetings under Dave and Steve's guidance and documented in this plan from where the appropriate parties will obtain their direction and responsibilities.

7 Risk & contingencies

Risk	**Contingency**	**Likelihood**	**Severity**
Pave feedthrus inadequate	Find alternative	1	3
Critical component lead time	?	?	2
Contamination, out gassing	Test in advance to catch problems; change materials; redesign	?	2
Intermittent electronic problems	Fix and repair as discovered	?	1
Leaks in dewar vessel & vacuum	Test in advance to catch problems; Repair and weld	1	1
Dark current not low enough	?	?	?
Charge bleeding a problem	?	?	?
Residual image significant	?	?	?

Likelihood and severity are rated from 1 (low) to 5 (high)

8 Work breakdown structure

The project work breakdown structure is shown in Figure 1. In outline form, the structure is as follows:

- 1 Critical Design
  - 1.1 Scientific requirements
  - 1.2 Systems design
  - 1.3 Optical design
  - 1.4 Mechanical design
    - 1.4.1 CCD H/W & backplane
    - 1.4.2 Dewar housing
    - 1.4.3 Coldfinger & vessels
    - 1.4.4 Electronics box mechanical
    - 1.4.5 VME crate structure
    - 1.4.6 Spider modifications
    - 1.4.7 Test fixturing
    - 1.4.8 LN2 Can
  - 1.5 Electronic design
    - 1.5.1 PCB layout
    - 1.5.2 Dewar electronics
    - 1.5.3 CCD controller
    - 1.5.4 Electronics box
    - 1.5.5 VME crate/chassis layout
    - 1.5.6 Power supplies
    - 1.5.7 Cable & harnesses
    - 1.5.8 Feedthrus & PCB connectors
  - 1.6 Software design
    - 1.6.1 CCD controller
    - 1.6.2 CCD controller timing board DSP
    - 1.6.3 CCD controller utility board DSP
    - 1.6.4 CCD VME crate
    - 1.6.5 VMEINF board DSP
    - 1.6.6 VME S/W for multi-CCD temperature servo loop
    - 1.6.7 Lickserve 2
    - 1.6.8 DS9 image display
    - 1.6.9 Config files for echelle simulator

- 1.6.10 Exposure control GUI
- 1.7 PDR
- 1.8 CDR
- 2 Evaluation and testing
  - 2.1 Test & characterize CCD's
  - 2.2 Evaluate Cryotiger
  - 2.3 Test PAVE connectors
  - 2.4 KECK site visits
- 3 Fabrication & Construction
  - 3.1 Field flattener fabrication
  - 3.2 Field flattener coating
  - 3.3 Mechanical fabrication
    - 3.3.1 CCD H/W & backplane
    - 3.3.2 Dewar housing
    - 3.3.3 Coldfinger & vessels
    - 3.3.4 Electronics box mechanical
    - 3.3.5 VME crate structure
    - 3.3.6 Spider modifications
    - 3.3.7 Test fixtures
    - 3.3.8 LN2 can
  - 3.4 PCD fabrication
  - 3.5 Electronic fabrication
    - 3.5.1 Dewar electronics
    - 3.5.2 CCD controller
    - 3.5.3 Electronics box
    - 3.5.4 Power supplies
    - 3.5.5 Cables & harnesses
  - 3.6 Cabling & wiring
  - 3.7 Software development
- 4 Assembly & Test
  - 4.1 Mount CCD H/W
  - 4.2 Mount CCD's on backplane
  - 4.3 Dewar mechanical assy
  - 4.4 First cool down test
  - 4.5 Extended cool down test(s)
  - 4.6 Electronics assy
  - 4.7 Wiring & routing
  - 4.8 Systems integration tests

5 Documentation
  5.1 Mechanical drawings
  5.2 Schematics & electrical drawings
  5.3 S/W code & documentation
  5.4 S/W help & reference documentation
  5.5 Part & equipment specs
  5.6 Test reports
  5.7 Pre-ship review
6 Shipping & Commissioning
  6.1 Logistics & insurance
  6.2 Dis-assy & tear down
  6.3 Packaging
  6.4 Assy & installation
  6.5 Test & commission
  6.6 Postmortem review

9 Milestones & deliverables

9.1 Milestones

Major Milestones	Comments	Date
Pave connectors tested	Completed early May 02	na
CCD's received		Jul/Aug 02
Field flattener fabricated		6/19/02
S/W mapped out	Flowcharts? Other…	Jan 03
Electronic design completed	Dewar electronics	9/6/02
	Electronics box	1/10/03
	Leach 2 VME Crate	na
	CCD Controller footlocker	3/21/03
CCD's tested & characterized		11/15/2
Mechanical design completed	Dewar	12/10/02
	Electronics box	2/14/03
	CCD controller footlocker	2/28/03
Field flattener coated	To be delayed as long as possible	*(3/28/0)3*
Design review 1	Preliminary design review	TBD

Major Milestones	Comments	Date
S/W completed	Rev 1 source code	4/9/03
PCB's received		TBD
Mechanical fab completed	Dewar	12/12/02
	Electronics box	3/17/03
	CCD controller footlocker	3/21/03
S/W tested		7/23/03
Electronic fab complete	Dewar	9/27/02
	Electronics box	2/7/03
	Leach 2 VME crate	9/18/02
	CCD controller footlocker	4/11/03
System vacuum test completed		TBD
Design review 2	Critical/Intermediate design review	TBD
Full system assembly		Jul 03
System testing completed		7/23/03
Pre-ship review		8/20/03
Packing complete		9/3/03
Ship		9/3/03
Commission		10/1/03

9.2 Deliverables

Deliverables	Comments
CCD controller S/W	
CCD controller timing board DSP S/W	
CCD controller utility board DSP S/W	
CCD VME crate S/W	
VMEINF board DSP S/W	

Deliverables	Comments
VME S/W for Motorola architecture	
VME S/W for multi-CCD temp. servo loop	
Lickserve 2 S/W	
DS9 image display S/W	
Config files for echelle simulator	
Exposure control GUI	
S/W documentation	
Field flattener, fab'd and coated	
CCD characterization	
CCD controller electronic	
Dewar electronics	
VME crate electronics	
Cabling	
Dewar vessel & CCD tray	
Coldfinger & cooling system	
Electronics box housing	
Mechanical drawing package/documentation	
Electronic schematics & drawings	
Shipping & packing equipment	
Test results	
System integration	

10 Schedule

Item	Task	Duration	Start	Finish
1	**Science Grade CCDs (3)**	**109.13 days**	6/17/02	11/15/02
2	Characterize and select CCDS	528 hrs	6/17/02	9/16/02
3	CCD metrology	225 hrs	9/17/02	10/25/02

Item	Task	Duration	Start	Finish
4	mount CCD hardware	1 wk	10/25/02	11/1/02
5	mount CCDs on backplane	2 wks	11/1/02	11/15/02
6	Documentation of existing dewar	30 days	12/27/01	2/6/02
7	Conceptual Electronics Design	86 days	3/1/02	6/28/02
8	**Dewar Design**	**181.5 days**	4/3/02	12/12/02
9	Electronic design	50 days	7/1/02	9/6/02
10	CCD board	6 wks	7/1/02	8/9/02
11	CCD board flex circuit	4 wks	8/12/02	9/6/02
12	Mechanical Design	1434 hrs	4/3/02	12/10/02
13	Mechanical Fabrication	920 hrs	7/5/02	12/12/02
14	Electronic Fabrication	3 wks	9/9/02	9/27/02
15	~~*Choice of LN2 or Cryotiger*~~			~~9/17/02~~
16	*Completion of Vacuum Dewar*			12/12/02
17	**Dewar electronics box**	**125.13 days**	9/9/02	3/17/03
18	Electronic design	80 days	9/9/02	1/10/03
19	analog switch board	6 wks	9/9/02	10/18/02
20	power board	4 wks	10/21/02	11/15/02
21	internal flex circuits	6 wks	11/18/02	1/10/03
22	Mechanical design	600 hrs	10/21/02	2/14/03
23	Mechanical fabrication	361 hrs	1/13/03	3/17/03
24	Electrical fabrication	4 wks	1/13/03	2/7/03
25	*Completion of Dewar System*			3/17/03
26	**Field Flattener**	**12.5 days**	6/3/02	6/19/02
27	Optical fabrication	100 hrs	6/3/02	6/19/02
28	*Completion of Field Flattener fab*			6/19/02
29	**Field Flattener coating**	**15 days**	*3/10/03*	*3/28/03*
30	Coating at LL[1]	120 hrs	*3/10/03*	*3/28/03*
31	**Leach 2 vme Crate**	**101 days**	7/8/02	11/25/02
32	Order parts/receive parts	6 wks	7/8/02	8/16/02
33	Electronic fabrication	100 hrs	9/2/02	9/18/02
34	software	240 hrs	10/15/02	11/25/02
35	*VME Crate Complete*			11/25/02

[1] The coating on the flattener will probably be delayed as long as possible, a date is provided only for convenience and completion of the schedule

Item	Task	Duration	Start	Finish
36	**Leach 2 CCD Controller**	**220 days**	7/8/02	5/23/03
37	Electronic design	50 days	1/13/03	3/21/03
38	CCD cable board	5 wks	1/13/03	2/14/03
39	CCD cabling	5 wks	2/17/03	3/21/03
40	order parts	8 wks	7/8/02	8/30/02
41	electronic fabrication	3 wks	3/24/03	4/11/03
42	software	240 hrs	4/14/03	5/23/03
43	*CCD controller complete*			5/23/03
44	**CCD controller foot locker**	**30 days**	2/17/03	3/28/03
45	mechanical design	80 hrs	2/17/03	2/28/03
46	mechanical fabrication	120 hrs	3/3/03	3/21/03
47	electronic fabrication	40 hrs	3/24/03	3/28/03
48	**Hires SW Upgrades**	**60 days**	1/15/03	4/9/03
49	Steve Allen	480 hrs	1/15/03	4/9/03
50	D Clarke	220 hrs	1/15/03	2/21/03
51	Bob Kibrick	480 hrs	1/15/03	4/9/03
52	**Assembly and test**	**72.5 days**	4/14/03	7/23/03
53	Assembly and test	12.5 wks	4/14/03	7/9/03
54	characterization	10 days	7/9/03	7/23/03
55	Pre Ship Review workup	4 wks	7/23/03	8/20/03
56	*Preship review*			8/20/03
57	Pack and Ship	10 days	8/20/03	9/3/03
58	*Ship date*			9/3/03
59	Commissioning	20 days	9/3/03	10/1/03
60	*Ready for first light*			10/1/03
61	Documentation	20 days	10/1/03	10/29/03

11 Revision history

This document is the project plan and as such will be continuously a work in progress and subject to constant revision. Revisions shall be noted on a two tier system in the following format:

XX.YY

The first number, XX, will denote a major revision change. This will involve document changes that will require mention in this section and trigger a message informing the project team of the revision.

The number YY represents the cumulative number of saves of this document. This number is a document parameter and automatically built into the page footer. This number will be incremented whenever changes are implemented. They can be as minor as format, spelling, or typo corrections.

Revision	Description
0	Rough draft development
1	Revised schedule (5/16/02) added; milestones updated; added MS Project file reference; revised introduction
2	Added Grant Hill to team; Removed references to CCR and use of Cryotiger by IGC Polycold; moved references to new network location
3	Added CARA requirements, Reference 13.7

12 Glossary

AR	Anti-reflection
CA	Clear aperture
CARA	California Association for Research in Astronomy
CDR	Critical design review; what's in name, this one is usually reserved for freezing the design
CFF	Conflat flange
CTE	Charge transfer efficiency
dark slide	Slow moving cover for dewar window
DS9	An astronomical imaging and data visualization application
DSP	Digital signal processor
FIGDISP	Mosaic display and de-scrambling software
H/W	hardware
LLNL	Lawrence Livermore National Labs
PAVE	Pave Technology, Inc.; Pressure and Vacuum Electrical Seals; pressure & vacuum electrical feedthru seals for automotive, aerospace, defense, industrial, marine, medical, & scientific applications
PDR	Preliminary design review
PI	Principal investigator

QA	Quality assurance
S/W	software
SDSU-2	Dewar boards from San Diego State University, 2nd revision (or generation); also known as Leach (after Bob Leach) boards
shutter	Fast moving (60 sec), controls CCD exposure, existing hardware at the slit
TBD	To be determined
Torr	Pressure equivalent to 1 mm column of mercury
VME	Or VMEbus (VersaModular Eurocard bus) is a bus (computer data path) system, designed by Motorola, Signetics, Mostek, and Thompson CSF, that is used in industrial, commercial, and military applications worldwide. VMEbuses are used in traffic control systems, weapons control systems, telecommunication switching systems, data acquisition, video imaging, and robots. VMEbus systems withstand shock, vibration, and extended temperatures better than the buses used in desktop computers, making them ideal for harsh environments.
VMEINF	VME Interface

13 References

13.1 *HIRES CCD Upgrade Project*, proposal to CARA, Steven S. Vogt, 29 October 2001

13.2 *Datatables*, mechanical drawings and project data spreadsheet, Excel worksheet, file location: tech/odin/loen_dwg2/hires/hires-ccd/general-distribution/datatables.xls

13.3 *Dim's & Values*, table of significant dimensions, values, etc., Excel worksheet, file location: tech/odin/loen_dwg2/hires/hires-ccd/general-distribution/datatables.xls

13.4 *Account Codes,* Excel worksheet, file location: tech/odin/loen_dwg2/hires/hires-ccd/general-distribution/datatables.xls

13.5 Hires CCD Upgrade Schedule, MS Project file, tech/odin/loen_dwg2/hires/hires-ccd/general-distribution/HIRES-5-16-02.mpp

13.6 *2 l/s Ion Pump*, Varian Vacuum Technologies, 87-900-091-01, March 2000

13.7 *HIRES CCD Upgrade CARA Requirements,* Grant Hill, www2.keck.hawaii.edu/inst/hires/upgrade/requirements

Figure 1
Work Breakdown Structure