W. M. Keck Observatory

Appendix A to
STANDARD CENTRALIZED PREDICTIVE AVOIDANCE PLAN

Revision B
November 03, 2009

Prepared by:
USSTRATCOM JFCC SPACE / J95
Vandenberg Air Force Base, California

24 Nov 2009

Randy Campbell
AO Operations Lead Astronomer
W. M. Keck Observatory

ANDREW C RITER, LTC, USA
Chief, Directed Energy Branch
Laser Clearinghouse Program Manager

1 INTRODUCTION

This appendix supplements the USSTRATCOM JFCC SPACE Standard Centralized Predictive Avoidance and Capability Validation Plan dated November 12, 2008 with specific information relating to the W. M. Keck Observatory lasers. This is not a stand-alone document and approval of this appendix entails acceptance of the entire plan.

1.1 Purpose & Scope.

No change to Standard Predictive Avoidance Plan, Section 1.1.

1.2 Background.

No change to Standard Predictive Avoidance Plan, Section 1.2.

1.3 Plan Maintenance.

No change to Standard Predictive Avoidance Plan, Section 1.3.

2 GENERAL DESCRIPTION OF SYSTEMS

2.1 Keck Observatory System Description.

Astronomers at the W. M. Keck Observatory probe the local and distant Universe from the summit of Hawaii's dormant Mauna Kea volcano. The twin Keck Telescopes are currently the world's largest optical and infrared telescopes. Each telescope stands eight stories tall, weighs 300 tons and operates with nanometer precision. The telescopes' primary mirrors are 10 meters in diameter and are each composed of 36 hexagonal segments that work in concert as a single piece of reflective glass. The W. M. Keck Observatory (WMKO) is jointly owned and operated by the University of California and the California Institute of Technology. The National Aeronautics and Space Administration is also an operating partner in the Observatory.

Figure A-1. Twin 10-meter telescopes of the W. M Keck Observatory

The Keck telescopes are pioneers in developing adaptive optics to overcome the effect of atmospheric blurring that distorts astronomical images. Adaptive optics relies on a laser guide star system using a special-purpose laser to excite sodium atoms that are chemically unbound in an atmospheric layer 90 kilometers above Earth. This creates an artificial "star" for measuring atmospheric distortions and allows adaptive optics to produce sharp images of celestial objects positioned nearly anywhere in the sky.

The Keck II telescope began science observations with a laser guide star adaptive optics system in late 2004, working in conjunction with the Laser Clearinghouse to obtain safe firing windows. A similar system is scheduled to be operational on the Keck I telescope by the end of 2009.

The laser systems will only be propagated between 12° evening twilight and 12° morning twilight and at an elevation above 20°.

Table A-1 lists the lasers used at the Keck Observatory.

Table A-1. Laser Parameters.

Laser Name	**CW Power or Pulse Energy** (Watts or J/pulse)	**Wavelength** (μm)	**Type** (CW or Pulse)	**P/A required?** (Yes/No)
Keck I	35 Watts	0.589	Pulsed	Yes
Keck II	20 Watts	0.589	Pulsed	Yes
CW = continuous wave				

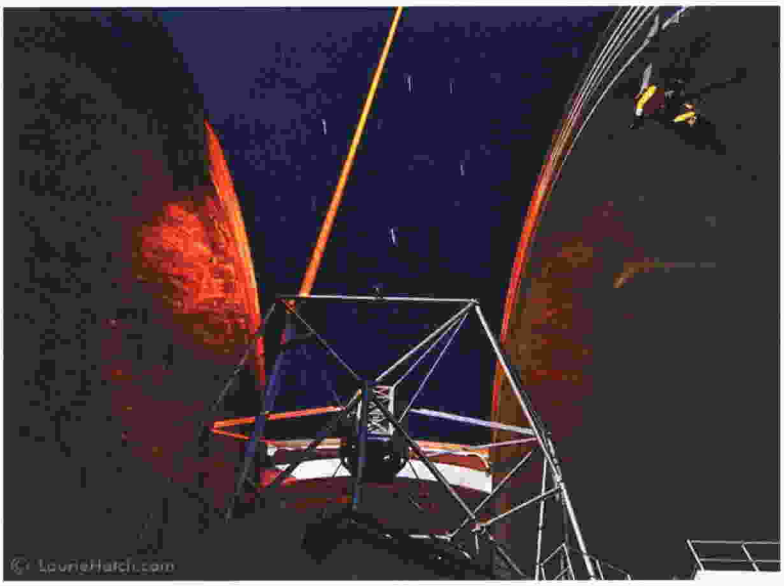

Figure A-2. Keck II laser propagation towards zenith

2.2 Laser Clearinghouse and Space Control Center Overview.

No change to Standard Predictive Avoidance Plan, Section 2.2.

3 LASER DECONFLICTION PLANNING PROCESS

No change to Standard Predictive Avoidance Plan, Section 3.

4 PROCEDURES FOR CENTRALIZED PREDICTIVE AVOIDANCE

4.1 Predictive Avoidance Planning.

The procedures of Section 4.1 of the Standard Centralized P/A Plan apply without change as listed in Table A-2 below. The table expands upon Table 1 of the Standard Centralized Predictive Avoidance Plan.

Prior to each night of laser firings, the Keck planning team prepares a Predictive Avoidance Request Message (PRM). The laser firing direction is defined in terms of azimuth and elevation or alternately in terms of Right Ascension and Declination. Numerous pointing targets of the same type may be requested in one PRM. Separate PRMs will be submitted for the Keck I and Keck II laser guide star systems.

Table A-2. Predictive Avoidance Planning Tasks.

Task	OPR	Description	Implementation
1.1	Keck	Determine test dates and times; identify lasers to be used and scenario.	Per Standard Plan. Added: The LCH may check the KECK schedule in lieu of 30-day prior coordination with Keck at the following URL. http://www2.keck.hawaii.edu/observing/schedule/index.php
1.2	Keck	Identify target or laser firing geometry; define target trajectory and uncertainties.	Per Standard Plan.
1.3	Keck	Transmit P/A Request Message to the LCH.	Per Standard Plan. Added: Transmit PRM 72-96 hours prior to laser usage.
1.4	LCH	Maintain MPL.	Per Standard Plan.
1.5	LCH	Maintain laser program's UPL.	Per Standard Plan.

In normal operation the complete PRM Message is provided to the LCH per the CPA Standard Plan no later than 72 hours, and preferably 96 hours prior to laser usage. However, occasionally the WMKO will have a scientific need to use the laser to study a celestial transient event. Examples of these objects are gamma ray bursts (GRBs), super novae (SN) or classical novae (CN). In the event of transient objects WMKO will resubmit the entire PRM coordinate list that includes the coordinates of the transient object (s). WMKO will note the reason for this list being resubmitted in the email and also call the SSA Ops to coordinate the transient event processing.

4.2 Predictive Avoidance Processing Activities.

The procedures of Section 4.2 of the Standard Centralized P/A Plan apply without change as listed in Table A-3 below. The table expands upon Table 2 of the Standard Centralized Predictive Avoidance Plan. The Joint Space Operations Center's Space Situational Awareness (SSA) Ops Cell is the primary point of contact for Keck predictive avoidance processing.

Table A-3. Predictive Avoidance Processing Tasks.

Task	OPR	Description	Implementation
2.1	SSA Ops Cell	Compute open windows based on request for P/A support.	Per Standard Plan. Added: Based on previous technical discussions, a 0.5° system contribution to the KOC plus Auto-coning is anticipated.
2.2	SSA Ops Cell	Transmit Open Windows in Predictive Avoidance Approval Message.	Per Standard Plan.
2.3	Keck	Determine if open windows are sufficient to support laser activity objectives.	Per Standard Plan.

4.3 Real-Time Laser Operations

The procedures of Section 4.3 of the Standard Centralized P/A Plan apply without change as listed in Table A-4 below. The table expands upon Table 3 of the Standard Centralized Predictive Avoidance Plan. This section describes the W. M. Keck Observatory predictive avoidance process during real-time laser operations.

Prior to laser fire, Keck operators use a software tool to import the Predictive Avoidance Approval Message (PAM), cross check laser pointing geometries, dates and times, and generate output files; one of which is compatible with the laser control system and another that in a format suitable for the laser safety operator to read easily by matching target names to open windows. If any errors are detected, WMKO will notify the SSA Ops Cell and cooperate to rectify any errors. The recomputed open windows / PAM files will be reprocessed as needed.

During laser firings, the firing control system uses graphical displays and sound warnings to alert the operator to open and closed firing windows. The firing times and geometries are manually verified by at least one person prior to laser firing being enabled. The firing may be terminated automatically via shuttering the laser by the firing control system or manually by the operators.

The software used at WMKO is described as having both a front end component and a back end component that are independent systems to provide safety redundancy. The back-end component is integrated into the more general laser safety permissive system. Each permissive input of the laser safety system must be true in order to permit laser propagation. The satellite permissive is only set true if the target coordinates match to within a tolerance of a 2 arc-minutes radius and the current time is within an open window. The frontend component has a more prominent user interface with graphical display and audio alarms to notify operators in cases of imminent closures. The display shows the timing statistics of the current open or closed window and will shutter the laser 6 seconds prior to the end time of an open window specified in the PAM file.

Upon manual confirmation of being within an open firing window, the laser can be manually propagated following either a back end or front end shutter event. A third layer of satellite avoidance is provided by the laser operator and science observers who plan laser usage only

within open windows. The laser operator will be ready to manually shutter the laser if either of the two software systems were to fail.

All data necessary for post-test predictive avoidance analysis are recorded by the system.

Table A-4 below expands upon Table 3 of the Standard Centralized Predictive Avoidance Plan.

Table A-4. Real-Time Laser Operations Tasks.

Task	OPR	Description	Implementation
3.1	Observatory Operators	Disseminate Open Windows for operator use.	Per Standard Plan.
3.2	Observatory Operators	Communication check and Laser Status Report.	Per Standard Plan. Added: This report can be made 60-15 min prior to planned lasing operations. See IER #4 in Table 5 of Standard Plan.
3.3	SSA Ops Cell	Space Event Notification.	Per Standard Plan. See IER #5 in Table 5 of Standard Plan.
3.4	Observatory Operators	Perform laser system processing of open windows to ensure a safe firing.	Per Standard Plan. Added: PAM open firing windows are imported and processed by a software tool.
3.5	Observatory Operators	Monitor laser beam and target position during engagement.	Per Standard Plan. Added: Performed by at least one Observatory Operators.
3.6	Observatory Operators	Abort / terminate laser firing if laser exceeds P/A spatial or temporal parameters.	Per Standard Plan. Added: Performed automatically by laser firing control system or manually by Observatory Operators.
3.7	Observatory Operators	Record laser firing data for post-test analysis.	Per Standard Plan. Added: Performed by laser firing control system.
3.8	Observatory Operators	Monitor status during engagement.	Per Standard Plan. Added: Performed by on-site Observatory Operators.
3.9	Observatory Operators	Quick Look Report.	Per Standard Plan. See IER #6 in Table 5 of Standard Plan.
3.10	Observatory Operators	Inadvertent Firing Notification.	Per Standard Plan. See IER #7 in Table 5 of Standard Plan.

4.4 Space Event Notification.

No change to Standard Predictive Avoidance Plan, Section 4.4.

4.5 Post-Test Assessments and Reporting.

The procedures of Section 4.5 of the Standard Centralized P/A Plan apply without change as listed in Table A-5 below. The table expands upon Table 4 of the Standard Centralized Predictive Avoidance Plan.

Laser firing data are recorded by the firing control system. The data are retained for future predictive avoidance use and locally archived for at least one year. A Laser Activity Summary Report (LASR) will be created and submitted to the LCH upon request or in response to an inadvertent firing.

Table A-5. Post-test Assessments and Reporting Tasks.

Task	OPR	Description	Implementation
4.1	Observatory Operators	Download (locally) post-test analysis data.	Per Standard Plan.
4.2	Observatory Operators	Send Inadvertent Firing Report to LCH. (if required)	Per Standard Plan. IER #8 in Table 5 of Standard Plan.
4.3	Observatory Operators	Compile post-test analysis data and send Laser Activity Summary Report to LCH (if required).	Required within 24 hours after an inadvertent firing per Standard Plan. IER #9 in Table 5 of Standard Plan.

5 INTEROPERABILITY AND COMMUNICATIONS INFRASTRUCTURE

The procedures in Section 5 of the Standard Predictive Avoidance Plan apply with the following additions:

Keck planning contact information:

Randy Campbell
Position: Adaptive Optics Operations Lead
Address: 66-1120 Mamalahoa Hwy, Kamuela, HI 96743
Unclassified Phone: 808 881-3867 (office) 808 557-6548 (cell)
Secure Phone: not available
Unclassified Fax: 808 885-4464
Secure Fax: not available
Email: randyc@keck.hawaii.edu
SIPRNet: not available

Secondary laser system contact information:

Name: Bob Goodrich
Position: Operations Manager
Address: 66-1120 Mamalahoa Hwy, Kamuela, HI 96743
Unclassified Phone: 808 881-3869
Unclassified Fax: 808 885-4464
Email: rgoodrich@keck.hawaii.edu

6 INFORMATION EXCHANGE REQUIREMENTS

No substantive change to Standard Predictive Avoidance Plan, Section 6, including Table 5.

7 PREDICTIVE AVOIDANCE CAPABILITY VALIDATION PROCESS

No change to Standard Predictive Avoidance Plan, Section 7.

The end-to-end predictive avoidance demonstration will be conducted to ensure that procedures and communications links between the LCH, Keck Planners, and Observatory Operators are sufficient to perform all P/A functions.

8 PREDICTIVE AVOIDANCE CAPABILITY VALIDATION CRITERIA

Table A-6 below expands upon Table 6 of the Standard Centralized Predictive Avoidance Plan.

Table A6 - Validation Criteria

#	Validation Criteria	Validation Documentation	OPR
1	LCH predictive avoidance capabilities identified in Section 4 have been satisfactorily tested.	**Completed** January 2007.	LCH
2	Laser predictive avoidance capabilities identified in this plan have been satisfactorily tested.	System and / or software test report showing how these requirements were met due 30 days prior to start of testing.	Keck Observatory
3	Verification of laser system parameters (laser positional uncertainty, laser optical beam divergence, laser beam spread caused by local jitter and atmospheric effects, boresight errors, and laser system failure modes) affecting the cone size for open window computation.	The LCH keep-out-cone half angle of 0.5 degrees for system uncertainties will be used. Keck will document the technical analysis showing whether the system's pointing abilities and failure modes are within this uncertainty threshold; due 14 days prior to the start of testing.	Keck Observatory
4	Interfaces, interoperability and procedures between the LCH and the laser operator including information exchange requirements have been verified.	Report of end-to-end P/A Demonstration of P/A capabilities conducted at least 21 days prior to authorization need date. See Appendix B of Standard Plan for the demo script.	LCH and Keck Observatory
5	P/A procedures have been developed, documented, and verified; and trained personnel are available.	Per Standard Plan, appendix C. Certification letter due 21 days prior to start of testing.	Keck Program Manager
6	DOD Compliance Statement whether the laser activity requires SECDEF approval.	Not Required	

9 PREDICTIVE AVOIDANCE RESPONSIBILITIES

9.1 Joint Functional Component Command for Space.

No change to Standard Predictive Avoidance Plan, Section 9.1.

9.2 Laser Clearinghouse (JFCC SPACE/J95).

No change to Standard Predictive Avoidance Plan, Section 9.2.

9.3 SSA Ops Cell (as tasked by LCH).

No change to Standard Predictive Avoidance Plan, Section 9.3

9.4 Keck Program.

No change to Standard Predictive Avoidance Plan, Section 9.4.

9.5 Air Force Research Laboratory/Satellite Assessment Center.

No change to Standard Predictive Avoidance Plan, Section 9.5.

APPENDICES B THROUGH D

No change to Standard Predictive Avoidance Plan appendices.

APPENDIX E - ACRONYMS AND GLOSSARY

Term	Definition
CN	Classical Novae
CW	Continuous Wave
CP/A	Centralized Predictive Avoidance
IER	Information Exchange Requirement
JFCC	Joint Functional Component Command
GRB	Gamma Ray Bursts
LASR	Laser Activity Summary Report
LCH	Laser Clearinghouse
MPL	Master Protect List
P/A	Predictive Avoidance
PAM	P/A Approval Message
PRM	P/A Request Message
SIPRNet	Secure Internet Protocol Router Network
SN	Super Novae
SSA Ops Cell	Space Situational Awareness Operations Cells, formerly referred to as the Space Battle Manager
UPL	Unique Protect List
USSTRATCOM	U.S. Strategic Command
WMKO	W. M. Keck Observatory