KAON # 755

Next Generation Adaptive Optics System

Laser Clearing House Planning

Preliminary Design

May 04, 2010

VersionV1.0

Prepared By Jason Chin

REVISION HISTORY

Revision	Date	Author (s)	Reason for revision / remarks
1.0	May 04, 2010	-	Preliminary Design Release

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1 INTRODUCTION

The Laser Clearing House (LCH) Organization has taken a leadership role in ensuring ground base hazards such as lasers do not damage satellite in earth's orbit. The LCH section works with the public to clear laser targets by providing windows of usage for the laser or closure if necessary. The Keck II laser system has been operating with support from the clearinghouse since its first light in December 2001. The Keck 1 laser system has come online in early 2010. Unlike the current single Keck 1 and K2 laser systems, the Next Generation Adaptive Optics (NGAO) System will propagate seven lasers in an asterism. This document provides an outline of issues that needs to be address for seven lasers operation.

Contact was established with Major Andrew Riter and his deputy, Lieutenant Heather Lehmann to discuss the NGAO laser system and its implications with LCH. The phone intercoms took place from May 2009 up to the preliminary design review.

2 References

2.1 Referenced Documents

Documents referenced are listed in Table 1. Copies of these documents may be obtained from the source listed in the table.

Ref. #	Document #	Revision or Effective Date	Source	Title
1	KAON 642	April 10, 2009	WMKO	NGAO Design Changes in Support of Build-to-Cost Guidelines
2	KAON 578	Feb 21, 2008	WMKO	Laser Clearing House Changes and the Affects on Keck LGSAO Operations
3		Rev B Nov 3, 2009	WMKO, LCH	Standard Centralized Predictive Avoidance Plan
4	KAON 702	May 20, 2009	WMKO	K1 LGS_0.589um_30W_1.03urad_80MHz

Table 1: Reference Document

2.2 Acronyms and Abbreviations

Table 2 defines the acronyms and abbreviations used in this document.

Acronym/Abbreviation	Definition
AO	Adaptive Optics
CPA	Centralized Predictive Avoidance Plan
FOV	Field of View
GUI	Graphical User Interface
KAON	Keck Adaptive Optics Note
LCH	LCH
LGS	Laser Guide Star
NGAO	Next Generation Adaptive Optics System
WMKO	W.M.K. Observatory

Table 2: Acronyms and Abbreviations

3 NGAO LASER ASTERISM

From the built to cost planning (KAON 642), the baseline LGS architecture that we have arrived at based on the elimination of a deployable integral field unit instrument is the following:

- A fixed LGS asterism consisting of one on-axis LGS and three fixed LGS symmetrically located on a radius, R. The optimal value of R is to be determined from analysis. This "3+1" asterism is used for laser tomography over the science field. A total of 50W of laser power will be distributed uniformly between these four LGS.
- Three movable or patrolling LGS to be used to sharpen the three natural guide stars used to provide tip-tilt information (one will also be used for focus, astigmatism and high order low bandwidth information). These LGS are used as part of single LGS AO systems. A total of 25W of laser power will be distributed uniformly between these three LGS.

The new LGS asterism is shown schematically in Figure 1.

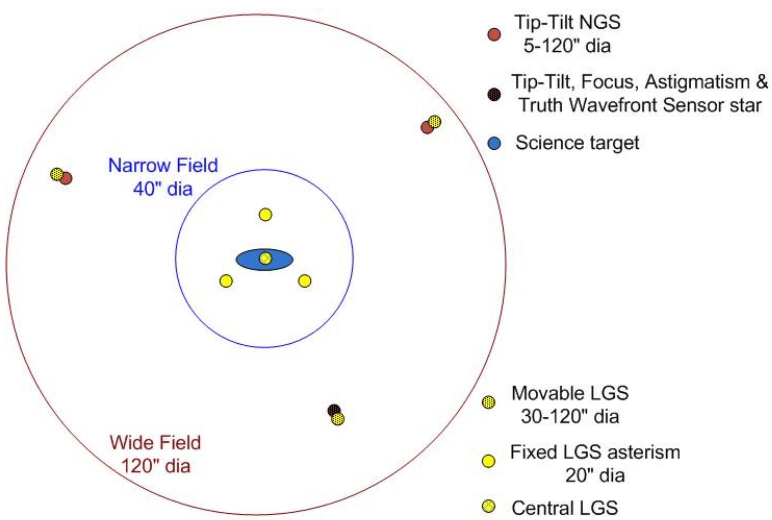

Figure 1 LGS "3+1" asterism for tomography of the science field, plus three patrolling lasers for image sharpening of the tip-tilt stars

4 EXISTING OPERATIONS

Existing operations of both the Keck I and Keck II lasers follow the procedures outlined in Standard Centralized Predictive Avoidance Plan (CPA). This plan was established by WMKO and the Laser Clearing House (LCH) in support of WMKO laser operations.

4.1 Keck II Laser Operations

It is the goal of the NGAO System to build on what is already established for the existing Keck II laser for laser operations (KAON 578). If possible, the same protocol will be followed. This section provides a description of the current laser operations.

Prior to propagation, WMKO works with the astronomer to provide a list of targets to LCH. The LCH processes this list of target using its *De-conflictation System* via its Spiral3 software. The software takes into consideration the parameters of the laser and determines closure windows for the submitted targets. A file is sent back to WMKO where a GUI processes and displays the closure windows. This will allow the astronomer to plan accordingly and provide advance notice of closure windows.

Within the last 15 months, the Spiral3 software was modified by LCH which significantly increased the number of closure windows for WMKO. Randy Campbell, WMKO LGS Operations Lead, worked with LCH to better define the laser parameters and behavior to reduce the number of closure windows.

By defining the NGAO's seven laser beams in the asterism as a single cone, the process of submission and maintenance of seven targets is simplified in both the submission and subsequent tracking process. Based on discussions with LCH, this is an accepted practice due to the small size of the NGAO asterism.

4.2 Laser Clearing House Software

There are two components to the LCH Spiral3 software calculations. The first component is the system contribution. The default system contribution keep out cone is a 2 ½ degree half angle. The second is the satellite ephemerides information. The default keep out cone due to the satellite ephemerides is 1 degree half angle. Based on this information, along with the laser format, the Spiral3 software generates the closure windows.

In the Keck II laser case, the default system contribution was reduced to a 0.5 degree half angle. This was done after reviewing the laser system pointing accuracies and error bars. The satellite ephemerides keep out cone was also modified by better estimating the satellite positions by LCH. Depending on the age of the ephemerides and the altitude of the satellites, more accurate satellite positions can be provided. By a combination of these two changes, the number of closure rates for the Keck II laser was reduced. NGAO should also follow this lead by reducing the keep out cone. This in turn will reduce the number of closures.

5 DESIGN CHOICES

The following are two design choices for addressing the asterism design.

5.1 Consideration of Seven Individual Beams

In this configuration, seven different reference beams for each field of view (FOV) must be submitted to the LCH. This will add consideration amount of work not only to LCH, but also to WMKO staff and astronomers for the seven fold increase in objects. WMKO will also have to provide the back end support for deciphering the closure times from many more targets.

The advantage of seven different beams may be that not all beams may be impacted at once. Some beams may not require a closure, thus, a minimal of science can be done with the remaining beams. A thorough investigation is needed if this design choice is chosen.

5.2 Consideration of a Cone of Laser Beams

In this configuration, a cone of +/- 60 arcsec represents the entire space of which the laser may reside. Based on an existing keep out zone of 1.5° half angle (KAON 578), the size of the beam cone is significant smaller by a factor of 90. Further discussions with Heather Lehman at LCH have initiated a keep out zone for the Keck I laser at 0.5° for initial alignments. Once the initial alignments are completed and shown to be reliable, this parameter can be reduced to 0.1°, similar to the operational value used for Keck II. Although the total power in the NGAO cone is significantly larger, the power density is no larger than any single beam since they do not overlap.

The advantage of using a cone is its simplicity and minimal changes to current operation procedures. It is unclear at this point whether the 0.1° will be increased due to the NGAO cone; however, the cone is still a factor of 6 smaller in term of radius and a factor of 36 smaller in term of area. Any increase may have an impact of higher closure rates. The NGAO team is recommending the use of a cone for LCH considerations instead of seven individual beams.

6 NGAO CONSIDERATIONS

Based on the initial discussions with Major Andrew Riter and his deputy, Lieutenant Heather Lehmann, LCH does not believe the NGAO laser asterism will present a significant problem due to the asterism size of +/- 60 arcsec. Similar cluster type laser systems exist and can be treated as a single beam of larger size. LCH wants to ensure the peak power is specified due to additive effect overlapping. A ten arcsec separation between beams does not increase the peak power due to overlapping beams. The power density will be based on a single CW laser with similar K1 laser beam divergence (KAON 702). The keep out zone may increase slightly due to the NGAO cone. Procedurally, WMKO can continue to operate as detailed in the CPA currently used for both Keck I and Keck II lasers. No additional change is requested.

NGAO has submitted a draft registration form which determined the NGAO lasers CANNOT be waived. As such, NGAO laser propagation can expect to follow the current protocol as outlined in the CPA for laser operations. Appendix A shows a completed registration form for NGAO submitted to the LCH.

7 MODIFICATIONS

There will be no impact to WMKO software or operational procedures if the single cone concept is adopted. However, final approval will be required prior to NGAO operations for a cone versus a single beam as well as different laser power and format prior to laser propagation.

8 PERFORMANCE AND IMPACT TO OPERATIONS

Any impact should be small based on the size of the cone versus the keep out zone.

9 DESIGN RECOMMENDATIONS

Base on discussions with LCH, no new design recommendations are necessary based on the simplicity of the laser cone design choice.

10 MANAGEMENT

10.1 Risk

During System Design Review, a risk was brought up regarding the dramatic increase of closures by LCH. The spiral software was changed in November of 2007 which initiated this risk. Since the event, Randy Campbell, AO Operations Lead, has been working closely to reduce the number of closures by reducing the keep-out zone and clarifying the Unique Protect List. The results can be seen in Figure 2. This same process can reduce the # of closures with data collected on NGAO pointing performance.

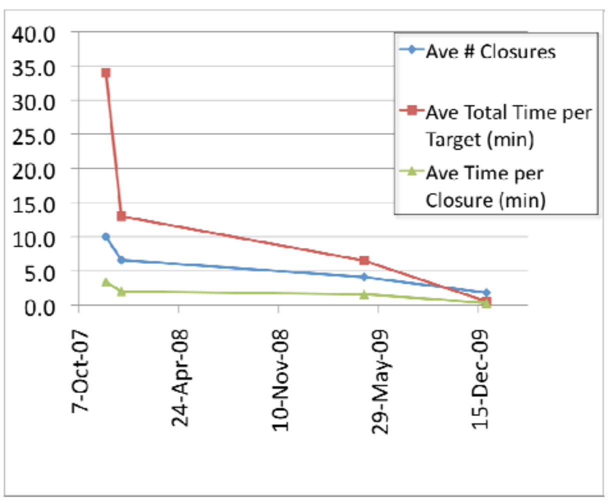

Figure 2: LCH Closure Rates for Keck II

10.2 Budget

A week of effort is needed to transfer and finalized plans with the LCH during the detailed design phase and confirm agreement for a laser cone of beams instead of individual beam.

10.3 Schedule

The schedule is flexible and should not propose an impact to the Detailed Design Phase.

11 Plans for Detailed Design Phase

For the DDR Phase, a tentative agreement will be worked out with LCH. A possible test can be done by sending a list of targets with the new geometry and compared against a single beam. Further discussions may be advantageous to reduce the number of closures by LCH.

Appendix A. NGAO LCH Registration Form Draft Submission

Please contact Jason Chin, jchin@keck.hawaii.edu, 808 881-3510

for additional information.

APPENDIX A: KECK II NGAO LASER REGISTRATION FORM

Laser Clearinghouse Information Sheet

JFCC Space J95/LCH, 747 Nebraska Ave, Room B209, VAFB, CA 93437
Unclassified Phone: 805-605-6565/6578 DSN: 275-6565
Secure Phone: 805-606-1075 DSN: 276-1075
Unclassified Fax: 805-606-1610

In registering your laser and asking for Laser Clearinghouse (LCH) assistance, you are confirming that the operation of your laser does not raise an issue of compliance with arms control treaty obligations and does not raise an issue of compliance with other international legal obligations**.**

If your laser is NOT waived, further coordination with LCH is required. A formal Predictive Avoidance Plan must be in place and signed through USSTRATCOM prior to support from LCH. In general, the laser registration sheet will expire in one year from date of submission. After this time, the sheet needs to be resubmitted with the most recent laser values. Waiver checks will occur every time a laser registration sheet is received.

The laser and platform values specified in this document must be "worst-case" values such that the values will not exceed the specified parameters. For example, the specified average laser power must not exceed the value stated. For further information about these laser parameters please see the description documentation which is available through the LCH. Any changes that cause the information to exceed the specified values require that a new laser registration form be submitted to the LCH.

A separate laser registration sheet must be filled out for each platform. It is encouraged to use a single form for a platform with many lasers and laser locations. If a single platform is transportable to other locations, please list these locations and ensure a unique name is given to each location. Also, try to use a single form to list multiple modes of a single laser.

SECTION I
Laser Site / Point of Contact

DATE: May 19, 2009

Laser Name/Modes (if applic.):	Keck II NGAO	
LCH Assigned Name:		
Classification of Laser/Mode:		

Classification of Laser site
Communicating w/LCH: Unclassified
Organization: W. M. Keck Observatory
Long Facility Name: W. M. Keck Observatory
Short Facility Name: WMKO
Point of Contact:

- **Name:** Randy Campbell, Bob Goodrich, Kenny Grace,
- Don Holdener, Stephan Shimko
- **Mailing Address:** W. M. Keck Observatory
  65-1120 Mamalahoa Hwy
  Kamuela, HI. 96743
- **Email address:** cmeLCHer@keck.hawaii.edu, randyc@keck.hawaii.edu, rgoodrich@keck.hawaii.edu, kgrace@keck.hawaii.edu, dholdener@keck.hawaii.edu, sshimko@keck.hawaii.edu
- **Phone (Commercial, unclassified):** 808-885-7887
- **Phone (DSN, unclassified):** None
- **Secure Phone # / Type:** None
- **Fax (unclassified):** 808-881-4464 & 808-935-1835
- **Secure Fax # / Type:** None
- **Emergency POC (name, phone and email):** On-Duty Observing Assistant at 808-935-8643 Or 808-881-3729

SECTION II
Platform Data

Platform Name: W. M. Keck Observatory, Keck II NGAO Laser Guide Star

Platform Type: Ground

Project Start Date: October 1, 2012

Project Completion Date: September 30, 2022

Typical Laser Target (check all that apply):

____Look-Angle _____Missile __X___Star _____Satellite _____Balloon _____Aircraft

___X___Other, explanation Fixed azimuth/elevation target for laser alignment and calibration

Comments:

SECTION III
Platform Location

The following specifies the location information for the laser platform. Please see the description document for the formats and types of information needed for each platform type (i.e. fixed, aircraft, space etc).

If the laser will be operated from multiple locations, please provide as many geodetic locations and unique location names as are known.

Location Name: Mauna Kea Summit Keck II

Fixed Site Location(s) (if applicable):

Lat 19.826561 North **(deg)** **Long** 155.474234 West **(deg)** **Alt** 4.16065 **(Km)**

Moving Platform Location (if applicable; free form, but should include range of latitudes, longitudes, altitudes and movement details):

Mobile Platform Description (A brief description of the mobile platform; specify specific satellite (if applicable) and other information as may be appropriate (particularly for maneuvering or non-orbiting space objects) to determine the possible pointing angles and locations of the laser platform):

Comments:

SECTION IV
Laser Parameters

The following information is applicable to all laser systems. The parameters with an asterisk (*) must be specified whereas the parameters without an asterisk will likely improve PA but are optional.

Please create several copies of the below tables for each laser associated with a given platform. This includes creating a new column or table for a laser that has several different operating modes. Note that each laser needs to have a unique name for each table of information; also, all values must be within the range for the double data-type: +/-1.7E308.

NOTE: Input all numerical entries below in an exponential format, e.g. 6.12E-06.

Item	Description	Constraints	Value 1	Value 2
*LN	Laser Name/mode		Keck II NGAO Laser Guide Star	
*LT	Laser Type	"Pulsed" or "CW"	CW	
*P	Pointer Aperture Average (Equivalent CW) Output Power (W). This is the total laser power that is transmitted away from the laser source. Note optics losses.	> 0.0	1.50E01	
τ_{ATM}	Maximum possible laser-to-space atmospheric trans-mission (usually assumed to be unity)	$0 < \tau_{ATM} < 1$	1.00E00	
$*\theta_{1/e}$	Divergence half-angle measured in micro-radians to equivalent circular Gaussian 1/e point (i.e., that beam radius encompassing 63.2% of the total beam power. Can list $1/e^2$ point if known). This will typically be the diffraction-limited beam divergence for a collimated beam or the controlled divergence angle, where larger, for intentionally diverging beams. (µrad)	> 0.0, Indicate if measured or calculated.	$1/e^2$ 1.45E00 (Calc) 1/e NA	$1/e^2$ 1/e
$*\lambda$	Center wavelength of the laser. (µm)	> 0.0	5.89E-01	
OQ	Beam quality (multiple of linear divergence above diffraction-limited value)	>= 1.0	1.25E00	
SR	Strehl ratio: ratio of irradiance at beam's center to	<= 1.0	6.50E-01	

Item	Description	Constraints	Value 1	Value 2
	diffraction-limited value			
*t	The maximum laser firing time. In other words, this would be the maximum time that the laser would be on for a given test. (sec)	> 0.0	1.44E04	
*H_{min}	Minimum laser operating altitude (km). Specified as the height above/below WGS84 ellipsoid where the laser is originating from.	> -6378.150	N/A	
*H_{max}	Maximum laser operating altitude (km). Specified as the height above/below WGS84 ellipsoid where the laser is originating from.	> -6378.150	N/A	
*BT	Beam Type (Specify one from each column, or use free form description for more detail) Top Hat (uniform) | Circular | Clear | Focused Truncated Gaussian | Ellipsoidal | Annular | Collimated Hyper-Gaussian | Rectangular | | Defocused Pure Gaussian | Square Other	N/A	Pure Gaussian Circular Clear Collimated	
*BC	Beam Count (If multiple beams are used)	> 1	7.00E00	
El_{min}	The minimum elevation angle that the laser could be pointed to (deg; above local horizontal)	-90 ≤ El_{min} ≤D 90	2.5E01	
El_{max}	The maximum elevation angle that the laser could be pointed to (deg; above local horizontal)	-90 ≤ El_{max} ≤D 90	9.0E01	
θ_{error}	Maximum laser pointing uncertainty and the slew angle the laser emits radiation during an emergency shut-off in inertial space (not relative pointing). Half angle (µrad)	> 0.0	8.72E02	
Turbulence	Specify if laser will only be used during conditions with some minimum level of atmospheric turbulence	> 0.0	-	

Comments: *The seven lasers are on an asterism within a field of +/- 290.89 urad. No two lasers are within 48.48 urad of each other. See Attached Diagram in Appendix.*
OQ and SR assume 1 for worst case calculations.

Circular Beams For circular beams, provide the following information as mandatory entries, provide additional comments below if necessary.

D	The primary aperture (exit pupil) diameter of the laser telescope (cm).	> 0.0	5.00E01	
D_{obs}	The diameter of a central, circular obscuration (if any) (cm).	0.0 ≤ D_{obs} ≤D	4.50E00	
w_{AP}	$1/e^2$ (and/or 1/e, indicate which) beam radius at the exit pupil (Gaussian, truncated Gaussian beams) (cm)	> 0.0	$1/e^2$ 1.90E01 1/e	$1/e^2$ 1/e
w_0	Beam Waist (cm). (Required for Gaussian beams)	> 0.0	9.3E00	
Z	Distance from aperture to Beam Waist (cm)	Any Value	8.20E06	

Item	Description	Constraints	Value 1	Value 2

Comments:

Ellipsoidal Beams For ellipsoidal beams, provide the following information as mandatory entries, provide additional comments below if necessary.

A	Major axis of primary aperture (cm)	> 0.0		
B	Minor axis of primary aperture (cm)	> 0.0		
a	Major axis of central obscuration (if any; cm)	> 0.0		
b	Minor axis of central obscuration (if any; cm)	> 0.0		
θ_{OBS}	Angle between major axis of obscuration and major axis of exit pupil (deg)	> 0.0		
w_a	$1/e^2$ (and/or 1/e, indicate which) semi-major beam axis (Gaussian and truncated Gaussian beams) (cm)	> 0.0	$1/e^2$ 1/e	$1/e^2$ 1/e
w_b	$1/e^2$ (and/or 1/e, indicate which) semi-minor beam axis (Gaussian and truncated Gaussian beams) (cm)	> 0.0	$1/e^2$ 1/e	$1/e^2$ 1/e
θ_{Beam}	Angle between major axis of beam and major axis of exit pupil (deg)	> 0.0		

Comments:

Rectangular Beams For rectangular beams, provide the following information as mandatory entries, provide additional comments below if necessary.

X	Long dimension of primary aperture (cm)	> 0.0		
Y	Short dimension of primary aperture (cm)	> 0.0		
x	Long dimension of central obscuration (if any; cm)	> 0.0		
y	Short dimension of central obscuration (if any; cm)	> 0.0		
θ_{OBS}	Angle between long dimension of obscuration and long dimension of exit pupil (deg)	> 0.0		
d_x	$1/e^2$ (and/or 1/e, indicate which) long half-dimension of beam (Gaussian and truncated Gaussian rectangular beams) (cm)	> 0.0	$1/e^2$ 1/e	$1/e^2$ 1/e
d_y	$1/e^2$ (and/or 1/e, indicate which) short half-dimension of beam (Gaussian and truncated Gaussian rectangular beams) (cm)	> 0.0	$1/e^2$ 1/e	$1/e^2$ 1/e
θ_{Beam}	Angle between long dimension beam and major axis of exit pupil (deg)	> 0.0		

Comments:

Square Beams For square beams, provide the following information as mandatory entries, provide

Item	Description	Constraints	Value 1	Value 2
additional comments below if necessary.				
X	Dimension across of primary aperture (cm)	> 0.0		
x	Dimension across central obscuration (if any; cm)	> 0.0		
θ_{OBS}	Angle between diagonal of obscuration and diagonal of exit pupil (deg)	> 0.0		
d	$1/e^2$ (and/or 1/e, indicate which) half-dimension of beam (Gaussian and truncated Gaussian square beams) (cm)	> 0.0	$1/e^2$ 1/e	$1/e^2$ 1/e

Comments:

Other Laser Parameters

Pulsed Lasers

For pulsed lasers, provide the following information as mandatory entries:

Item	Description	Constraints	Value 1	Value 2
Pulse Format	Description of the laser pulse format (e.g. single pulse, repeating pulse, double pulse, etc).	N/A		
E_{PULSE}	Energy per pulse (J/pulse)	> 0.0		
Pulse Shape	Rectangular, sawtooth, spike + tail (including energy fractions in each), etc.	N/A		
t_{PULSE}	Pulse duration (sec) and criterion (FWHM, beginning-to-end (BE), etc)	> 0.0		
PRF	Pulse repetition frequency (kHz)	> 0.0		
P_{INST}	Instantaneous single pulse peak power (W)	> 0.0		
$P_{EQUIV\ CW}$	Equivalent CW Power or Average Power (W)	> 0.0		

Comments:

Focused Lasers

If a laser focuses to a point in space rather than trying to provide a collimated beam that focuses at infinity, then the laser operator must specify the following information:

Item	Description	Constraints	Value 1	Value 2
D_{MAX}	Maximum laser pointer exit pupil dimension (cm)	> 0.0	5.00E01	
$R_{FOCUS\ MIN}$	***Minimum*** focus range (km)	> 0.0	8.00E01[*1]	
$R_{FOCUS\ MAX}$	***Maximum*** focus range (km)	$R_{FOCUS\ MAX} \geq R_{FOCUS\ MIN}$	1.50E02[*2]	

Comments:

[*1] These values are referenced to the laser projection location at 4.19km above sea level. The min/max are based on the elevation angles and are distances to the sodium layer at 90km above sea level.

Appendix B. NGAO Laser Architecture

The baseline LGS architecture is the following:

- A fixed LGS asterism consisting of one on-axis LGS and three fixed LGS symmetrically located on a radius, R. The optimal value of R is to be determined from analysis. This "3+1" asterism is used for laser tomography over the science field. A total of 50W of laser power will be distributed uniformly between these four LGS.
- Three movable or patrolling LGS to be used to sharpen the three natural guide stars used to provide tip-tilt information (one will also be used for focus, astigmatism and high order low bandwidth information). These LGS are used as part of single LGS AO systems. A total of 25W of laser power will be distributed uniformly between these three LGS.

The new LGS asterism is shown schematically in Figure 3.

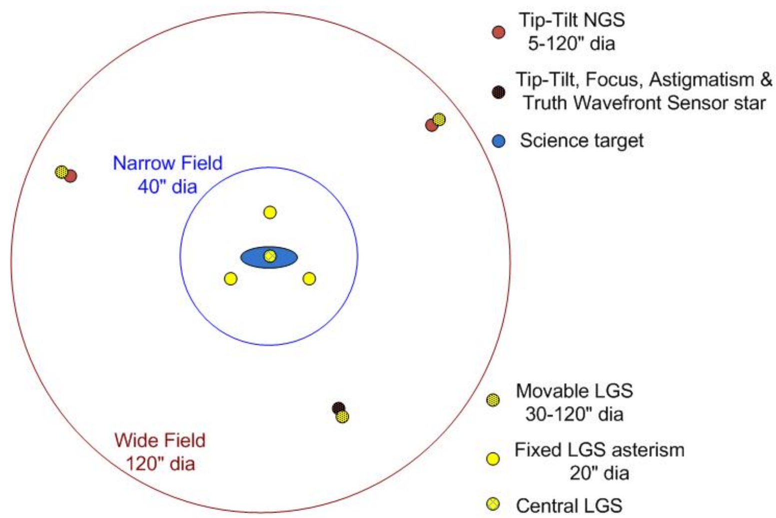

Figure 3 LGS "3+1" asterism for tomography of the science field, plus three patrolling lasers for image sharpening of the tip-tilt stars