Status of Subaru Laser Guide Star Adaptive Optics Project

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1. INTRODUCTION

A new adaptive optics (AO) system is under development at Subaru Telescope. The system is equipped with a laser guide star (LGS) and installed on the Nasmyth platform. The AO configuration is a combination of curvature wavefront sensor and bimorph deformable mirror, controlled at 1k Hz sampling speed. The number of the control elements is increased to 188, which realizes higher Strehl ratio in an observing band and improves the performance at shorter wavelengths, compared with the previous 36-element AO system.

The first on-sky closed-loop operation was demonstrated in October, 2006 in the natural guide star (NGS) mode. After development and improvement of optomechanical components and software, risk-shared open-use observation of the NGS mode was started in October, 2008, and then usual open-use in February, 2009. The Strehl ratio of 0.55 has been achieved in the K-band using an 8th magnitude NGS at 0.4 arcsec seeing. Regarding the LGS mode, we were successful to generate an LGS on sodium layer and observe it by a camera in the wavefront sensor in February, 2009. The total equivalent magnitude of the LGS was estimated as 10.7 mag, though the FWHM was around 2 arcsec when seeing was 1.3 arcsec in the K-band. The next step is to close loop on LGS using the low order wavefront sensor.and LGS tip/tilt control.

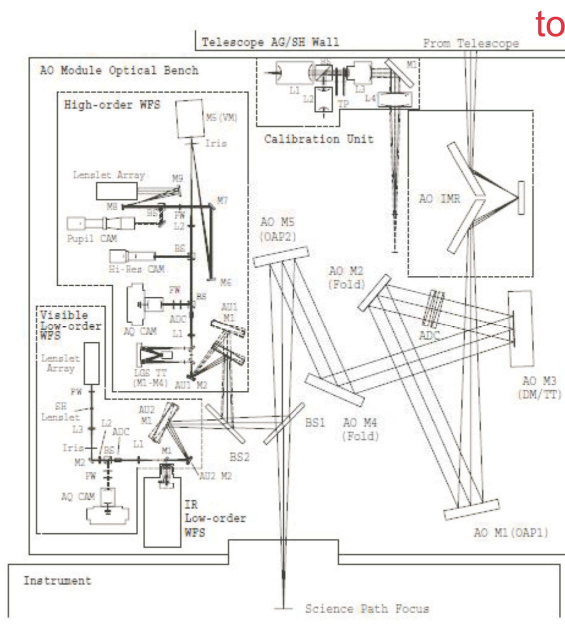
2. AO188 system

2.1 AO module

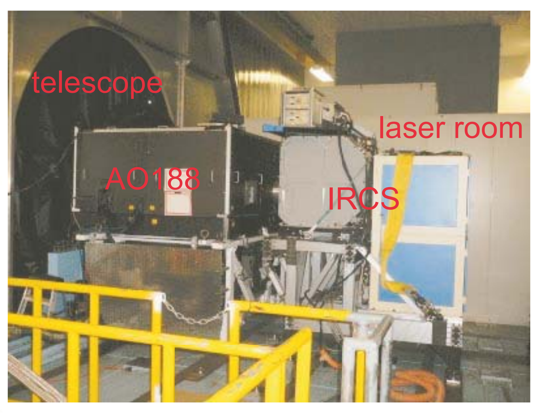
Watanabe et al.(2004),Proc.SPIE,5490,1096

Optics	F13.9, beam ϕ=90mm FOV = 2' (2.7' for WFS)
Spectral coverage	0.45-5μm
Wavefront sensor	curvature sensor 188 photon counting APDs
Deformable mirror	bimorph PZT mirror 188 control electrodes stroke: +/- 10m (global)
Tip/tilt mount	voice coil stroke: +/- 5" (on sky) holding DM mount
Control bandwidth	> 100Hz > 1000 correction/sec

AO module top view



side view

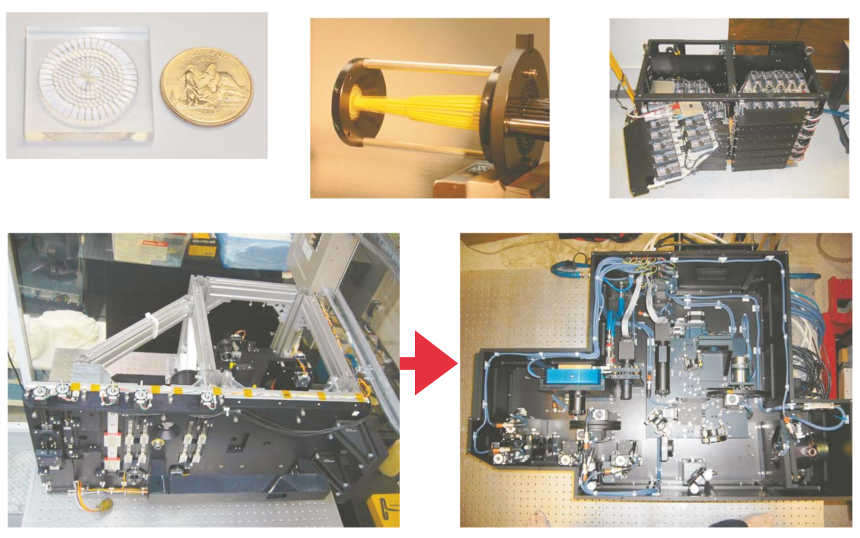


The accurate positions of representative screw holes on optical bench were measured from the two side of the bench by caliper and used as positional reference to place optics on the bench with the accuracy of 0.1mm. Each optical component is secured on the bench at three contact points

2.2 High Order Wavefront Sensor

Watanabe et al.(2008),Proc.SPIE,7015,64

The type of WFS is curvature sensing. The beam modulated by vibrating mirror, is divided by lenslet array with 188 elements. The photons in each element is transfered by mulimode fiber (core diameter 200μm) to APD (avalanche photo diode) and counted. Optoemchanical structure has been thoroughly re-designed and fablicated after the first light in October 2006, to improve stablitiy of the system.

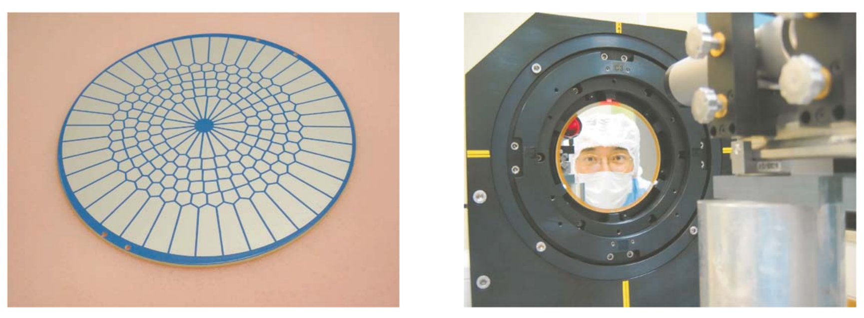


before after

2.3 Deformable Mirror

Oya et al.(2006),Proc.SPIE,6272,4S (DM design)

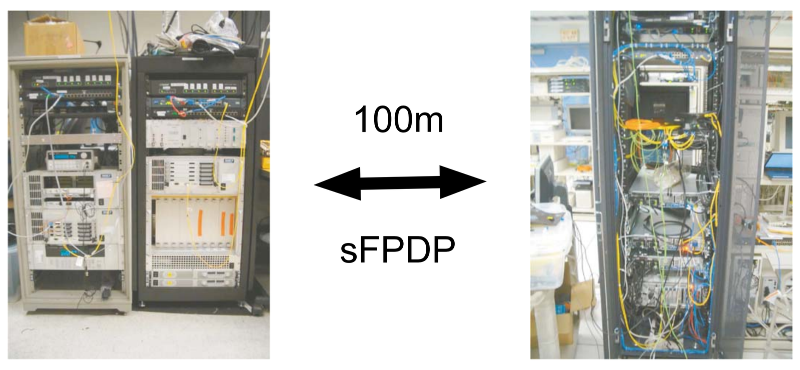
The type DM is bimorph made of PZT with 188 electrodes. The diameter of the blank is 130 mm and the thickness is 2.0 mm including glass plate bonded on each side. The surface is polished to achieve λ/20. Maximum curvature achivable within voltage range is +/-400 [V] is +/-1/(10m) for global curvature and +/-1/(16m) for local curvarure by one electrode. The DM is mounted on a tip/tilt mount (TTM) which has +/-3.7 arcmin mechanical stroke and +/-5 arcsec stroke on sky.



2.4 Control System

Hattori et al.(2006),Proc.SPIE,6272,5G (Control)

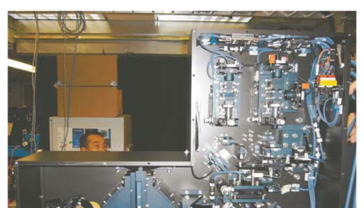
The electronics racks are placed on the Nasmyth platform, while the control computers are in the control building separated by 100m. They are connected by SerialFPDP protocol on opticsl fiber with data transfer rate of 2 Gbps. The realtime control system has 4 CPUs (2.0GHz Xeno) and one of them is dedicated for loop calculation.



Electronics Computers

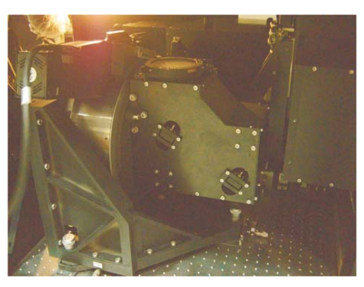
2.5. Optomechanical Components

2.5.1 Calibration Unit



The callibration unit has LDs and delivers visible light (655 nm) and infrared light (1550 nm) with the same f-number as the telescope. Two retractable turbulence plates are installed and controlled independently.

2.5.2 Image Rotator



Only one rotator stage is used to avoid complicated alignment between two rotation stages at both end of the IMR mirror unit composed of 3 mirrors configured in 'K' shape. The tracking file of IMR angle is calculated independent of the telescope status, based on the object coordinates (RA,DEC) and NTP-synchronized time. The tracking is based on the position control (stop-and-go) with small step size (0.004deg).

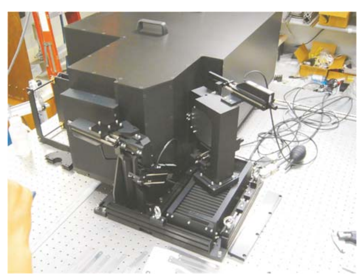
2.5.3 Atmospheric Dispersion Corrector (ADC)

The ADC is under development. The system will be controlled in a similar manner as IMR.

2.5.4 Beam Spliter exchange mechanism

The mechanism can carry 3 types of beam splitter (BS). The first one is usual BS which reflects visible light to WFS and transmits infrared light to host instruments (IRCS,HiCIAO). The second one transmits a part of visible light to a host instrument (Kyoto3D). The third one reflects a part of infrared light to WFS side for future plan of infrared WFS.

2.5.5 Acquisition Unit (AU)



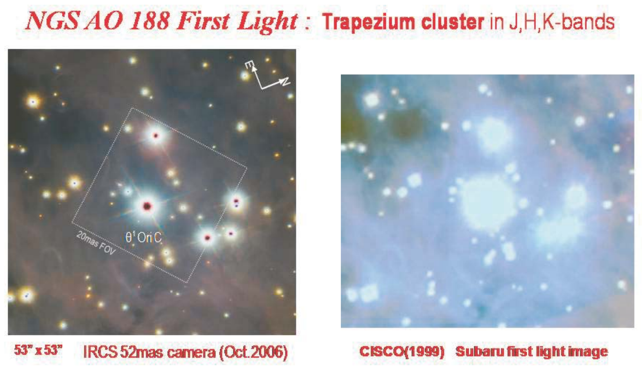
The AU pick up a guide star in FOV and feeds the light into WFS. The acquisition unit consists of two tip/tilt mirrors to keep correct position and tilt of incident light to WFS. The first mirror of the two is installed on a linear stage to adjust focus. In addition to the existing acquisition unit for HOWFS, the acquisition units will be also prepared separately for low order wavefront sensor.

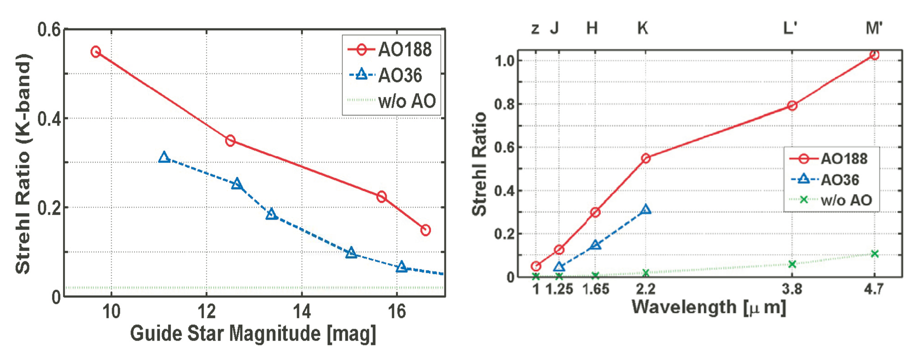
2.6 Performance and Status

http://www.subaru.nao.ac.jp/Observing/Instruments/AO/performance.html

The AO188 system can work as an NGS AO system. The NGS mode has been opened for common-use observation program since February, 2009.

NGS AO 188 First Light : Trapezium cluster in J,H,K-bands





4. Host Instruments

Takami et al.2006,Proc.SPIE,6272,0C

- IRCS (working at Nasmyth focus now)
http://www.subaru.naoj.org/Observing/Instruments/IRCS/index.html

- HiCIAO (hi-contrast CIAO)
Tamura et al.(2006),Proc.SPIE,6269,0V

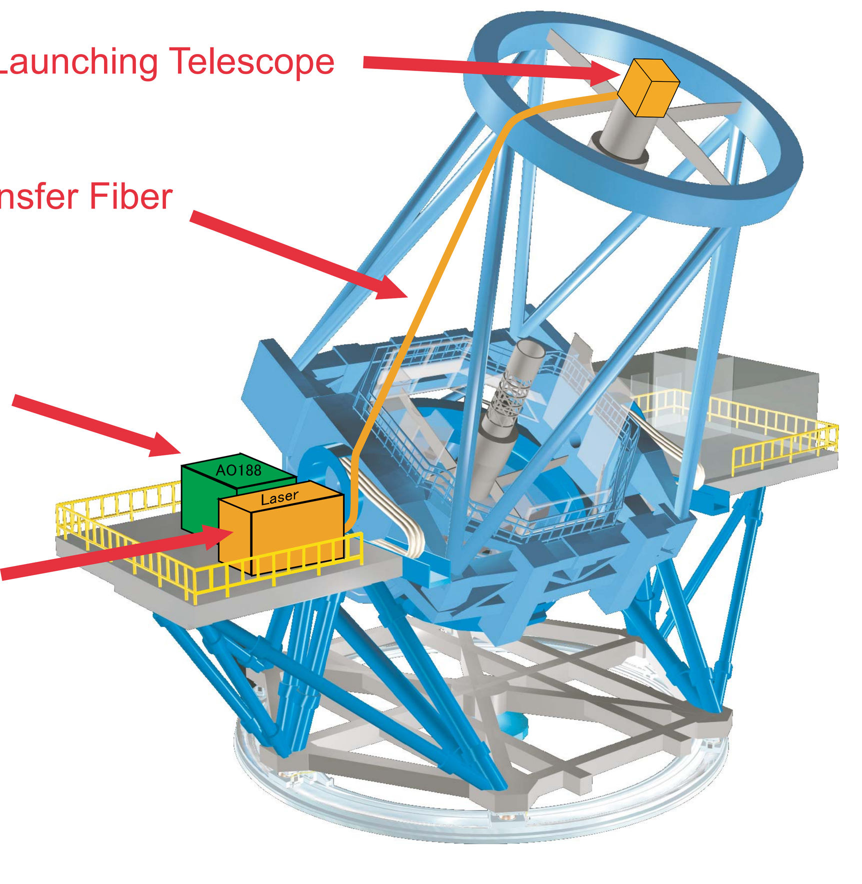
- Kyoto3DII: Kyoto tridimensional spectrograph II
Sugai et al.(2006),NewAR,50,358

3. LGS system

3.1 System Overview

Hayano et al.(2006),Proc.SPIE,6272,47 (LGS system)

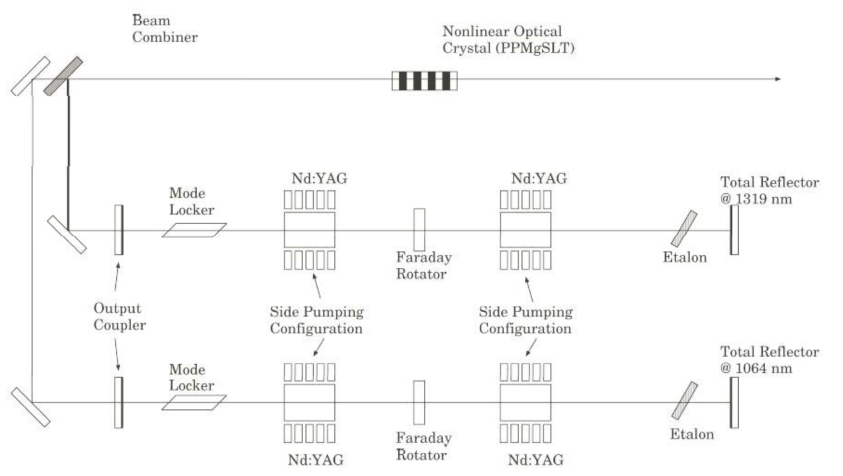
Laser	all solid-state sum-frequency mode locked NdYAG 1064nm (16W) + 1319nm (5W) → 589nm (4.5W) M^2<1.1
Optical fiber	single mode PCF core ϕ=14μm, length:35m
Launching telescope	ϕ=50cm beam expander angular mag.: 12.5, FOV=2' attached on the back side of secondary mirror of Subaru



3.2 Laser

Saito et al.(2006),Proc.SPIE,6272,46 (Laser)

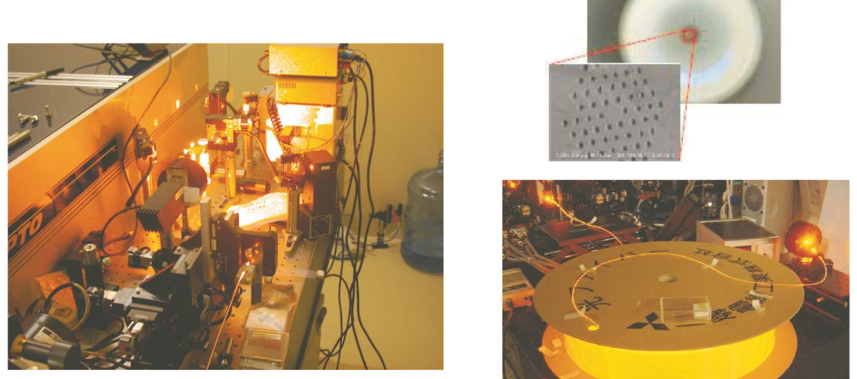
The type is all-solid sum-frequency laser, which generates 598nm light from two wavelengths (1064nm and 1319nm) of Nd:YAG laser by non-linear effect of a crystal. The output beam is pseudo-continuum (0.8ns width and 143MHz repetition frequency) because of mode-locked operation. The beam quality is M^2 < 1.1.



3.3 Fiber

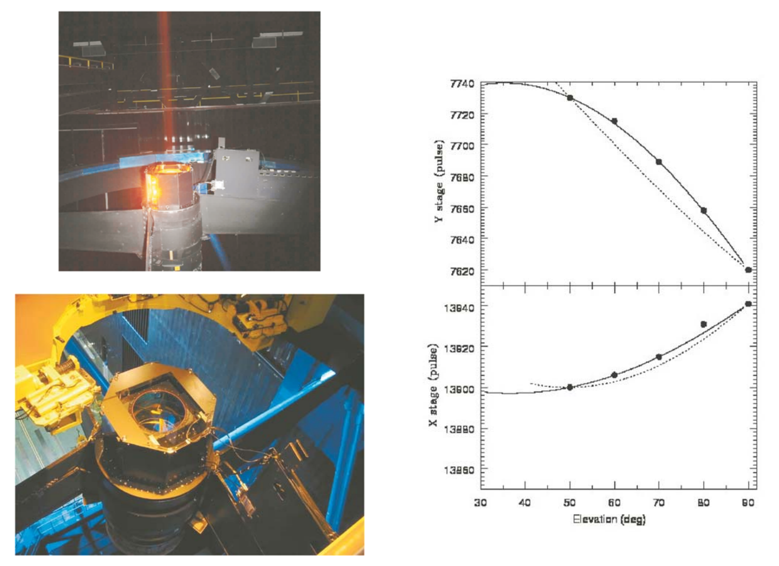
Itoh et al.(2006),Proc.SPIE,6272,45 (Optical fiber)

The laser transfer by an optical fiber is alignment-free and not affected by telescope position. On the other hand, fine adjustment (order of 0.1μm) is required at the coupling point between laser beam and fiber. The type of the fiber is PCF. The which has larger diameter than usual single mode fiber. As a result, the energy density in the fiber decreases which is effective to avoid non-linear scattering effect, i.e., stimulated Raman scattering and stimulated Brillouin scattering.



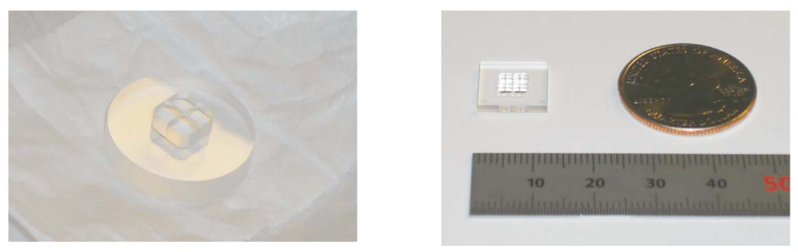
3.4 Laser Launching Telescope

The LLT is a beam expander with on-axis configuration. The output aperture diameter is 50 cm and the magnitude is 12.5. The LLT is attached on the back side (sky side) of the secondary mirror of Subaru Telescope. The relation between the direction of LLT and Subaru Telescope changes with EL angle of Subaru Telesocpe due to flexure. The LLT has beam steering optics at the entrance to compensate the mis-alignment. The steering optics position are calibrated as a function of EL angle, based on data gathered during the engineering observations in February 2009 by changing EL angle along north AZ angle. The validity of the function will be checked all over the sky in the next engineering observation run.



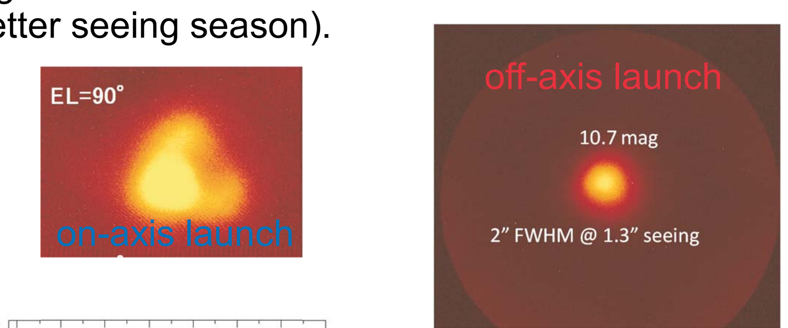
3.5 Low Order Wavefront Sensor

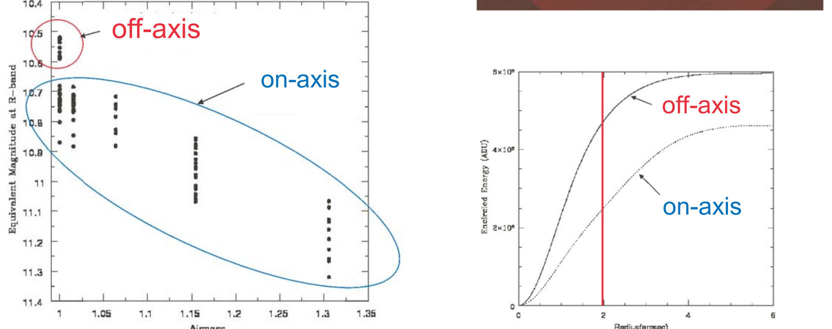
The LOWFS is under development. The basic design is 2x2 Shack-Hartman ensor. Instead of using 2D array detector, the spot of each subaparture is also divided by 2x2 lenslet array and detected by fiber-coupled APDs.



3.6 Performance and Status

We were successful to generate a sodium LGS and observe it by a camera in the wavefront sensor in February, 2009. The total equivalent magnitude of the LGS was estimated as 10.7 mag, as expected. The LLT still has a certain amount of aberration near the center obscuration (around tertiary support), which generate horn-shaped peculiar pattern when the peak of output Gaussian beam is set to the center axis. The patten faded out when the peak is set off the center axis so that the most intensity of the beam passed through good figure area of the LLT. Even after focus adjustment in addition to the beam offset, the best FWHM of LGS was no smaller than 2 arcsec. This is probably due to the bad seeing condition (1 arcsec in the K-band). Smaller size is expected during for the next engineer observation run scheduled in this summer (better seeing season).





5. Schedule

(1) Engineering Observations
6/1-4, 7/24-27, Sep., Dec., Jan. in S09B
(2) Installation of components under development
after S10A