The First Light of the Subaru Laser Guide Star Adaptive Optics System

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ABSTRACT

The overview and the first light result of the laser guide star adaptive optics (AO188) system for Subaru Telescope is presented. It is installed at the IR Nasmyth platform of Subaru 8 m telescope, whereas the current AO system with 36 elements is operating at the Cassegrain focus. The new AO system has a 188 element wavefront curvature sensor with photon counting APD modules and 188 element bimorph mirror. It has a 4.5 W solid state sum-frequency laser on the Nasmyth platform. The laser launching telescope with 50 cm aperture is installed at behind the secondary mirror. The laser beam is transferred to the laser launching telescope using photonic crystal single mode fiber cable. The instrument with the AO system is IRCS, infrared camera and spectrograph which has been used for Cassegrain AO system and new instrument, HiCIAO, high dynamic range infrared camera for exoplanet detection. We had the first closed loop on sky in October 2006 and projected laser to the sky at the same observing run.

1. INTRODUCTION

The Subaru new AO system is a 188 element curvature sensor AO system with laser guide star. We already have a 36 element curvature sensor located at the Cassegrain focus, and has been in operation since December of 2000 [1]. The instruments working with the AO system are IRCS [2] (InfraRed Camera and Spectrograph, Grism spectroscopic mode, R=1000, 23 and 58 mas/pix, Echelle spectroscopic mode, R=20000, 60 mas/pix, 1k x 1k InSb detector) and CIAO [3] (Coronagraph Imager with AO, 11 and 22 mas/pix, 1k x 1k InSb). The AO system is working routinely and 40 science papers have been published so far. However, the 36 element system becomes less competitive because of the lower order correction and we can only observe a limited number of objects. Therefore we have started the project to build a higher order AO system with laser guide star capability. The project was funded in 2002 by Grant in aid of MEXT (Ministry of Education, Culture, Sports, Science and Technology).

2. SYSTEM DESCRIPTION

1) Overview of the System

The AO188 module will be mounted on the Nasmyth platform (IR side, 8 m x 8 m), as shown in Fig.1. The system is based on a curvature wavefront sensor with 188 sub-apertures. This is the highest correction order among the curvature sensor AO systems. The system is mounted on the 1.72 x 2.1 m optical bench. The detail layout is shown in the paper of Watanabe et al. 2004 [4]. The beam diameter is 90 mm. The F-number of the Nasmyth focus is 13.9. The field of view of the optics covers 2.7 arcmin on the sky. We use this field optics mainly to acquire tilt guide stars in laser guide star AO operation. The calibration light source which generates both natural guide star light and laser guide star light with artificial atmospheric turbulence is equipped. An image rotator unit is also equipped on the AO optical bench.

The laser system is also installed at the Nasmyth floor. The laser beam is transferred to the laser launching telescope through a single mode photonic crystal optical fiber with 14 μm core diameter. The laser launching telescope with 50 cm aperture size is mounted on the back side of the telescope secondary mirror.

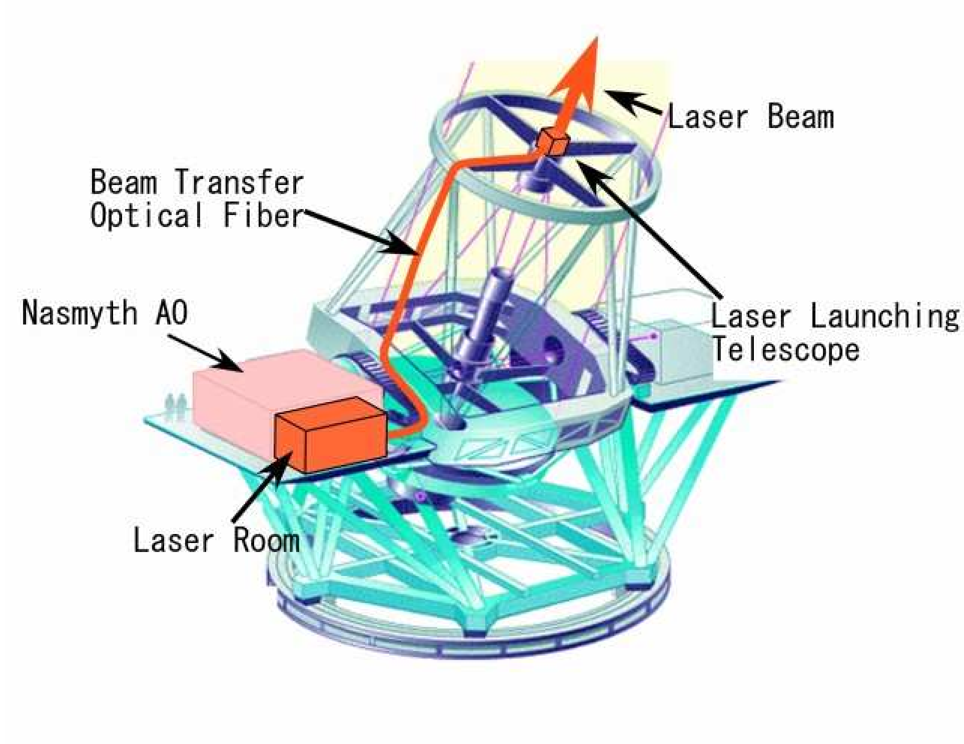

Fig. 1. Overview of Subaru laser guide star adaptive optics.

Fig. 2. The AO system on Nasmyth platform. The left black box is AO and the right one is IRCS. There is a clean room for the laser is behind the AO and IRCS.

Table 1. Specification of Subaru laser guide star AO system

Location of the system	Nasmyth focus (IR)
Number of elements	188
Deformable mirror	Bimorph mirror with 188 elements, 90 mm beam diameter, 130 mm blank
High order WFS	size
Low order WFS (visible)	Curvature sensor with APDs , 3.5 arcsec FOV
Low order WFS (IR)	2 x 2 Shack-Hartmann sensor with 16 APDs for TT and defocus
Main Optics	Pyramid or SH WFS (TBD)
Laser	2.7 arcmin FOV, F/13.9
Beam transfer optics	Sum frequency generation 4.5 W @589 nm, 10-11th magnitude
Laser launching telescope	Single mode photonic crystal optical fiber with 14 μm core diameter
Real time computer	50 cm telescope diameter behind the secondary
Control speed	4 Xeon CPUs (2.0GHz) with real time Linux OS
	1500 corrections/sec

2) Wavefront Sensor

The curvature wavefront sensor with 188 elements is used for the high order wavefront measurement (HOWFS). The detectors are SPCM-AQR photon-counting APDs manufactured by Perkin-Elmer. A lenslet with 188 elements is used. Optical fibers is placed at the focus of each subaperture and feed to the APDs (Fig. 3). The core diameter of the fiber is 200 μm and the field of view is 3.5 arcsec. The lenslet material is made of plastic which is replicated from copper mold made by precise diamond machining technique.

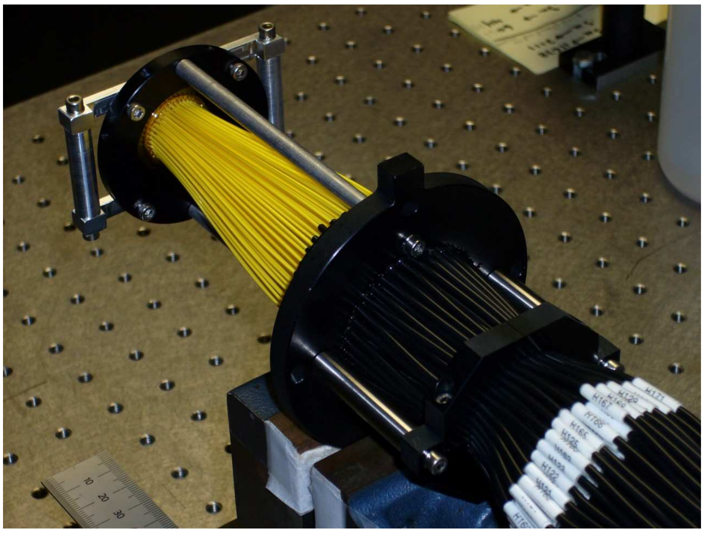

Fig. 3. 188 fiber bundle assembly. Core diameter of the fiber is 200 μm.

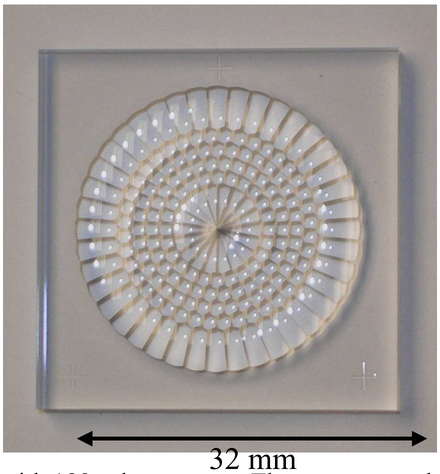

Fig. 4. Plastic mold lenslet array with 188 sub-apertures. The copper metal mold is manufactured by diamond turning machine. The typical spacing between each lenslet is 1.2 mm.

We also need a natural guide star wavefront sensor (low order WFS) to measure wavefront tilt and defocus. Those guide stars can be fainter than required for HOWFS. We use 2 x 2 Shack-Hartman wavefront sensor to measure the wavefront tip/tilt and defocus using 16 photon counting APDs. It has slight decrease of the throughput compared to the SH sensor with CCD because of the optical fibers, however it is adequate for fainter guide stars because it uses zero readout noise APDs.

IR low order wavefront sensor is also developed collaborating with Max Plank Institute for Astronomy (Heidelberg). It is very powerful for observing dark cloud regions where the natural guide stars are not usually available [5]. High order WFS capability is also investigated.

3) Deformable Mirror

The bimorph type deformable mirror (DM) with a 90 mm effective aperture and the mirror blank size of 130 mm is manufactured by CILAS. The detail report is shown in Oya et al. 2006 [6]. The key issue in designing the bimorph deformable mirror for high order adaptive optics system is to provide large curvature stroke keeping the resonance frequency high enough for stable closed loop control. While the curvature stroke will increase when the thickness of mirror is reduced, the resonance frequency decreases proportional to the thickness of the mirror. We have selected new piezo material P188 with higher stroke than their standard material. The material has 20% hysteresis, but the effect is small for closed loop operation.

The measured stroke is +/- 11~16 m which is larger than the specification (+/- 33 m) to have "20% Strehl loss" at 1.3 arcsec seeing. The measured main resonance frequency determined by the material size is 641 Hz. We also observed smaller resonance at 124, 214, 457 Hz. They are reproduced by our FEM analysis. The resonance is considered to be produced by the existing 3 points support mechanism. We are investigating supporting structure design and control algorithm to dump those resonances. The mirror is mounted on a voice-coil type fast tip/tilt mount manufactured by Observatoire de Meudon, in France.

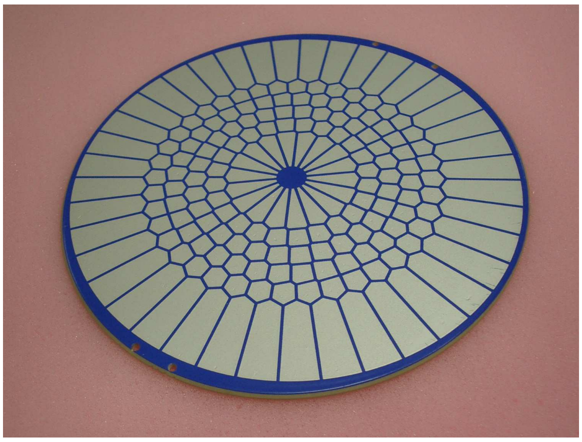

Fig. 5. The inner electrode pattern of 188 element bimorph mirror (BIM188). The pattern is not seen after completion of the mirror.

Table. 2. Parameters of 188 element bimorph deformable mirror

PZT material	P188
Surface glass material	BK7
Effective aperture	90 mm
Blank diameter	130 mm
Number of electrodes	188 (40 electrodes for outer ring)
Thickness	<2.0 mm (PZT 1.8 mm, glass <0.2 mm)
Applying voltage	+/- 400 V
Curvature Stroke (measured)	+/- 11 ~16 m
Resonance frequency (measured)	641 Hz (main), 124, 214, 457 Hz.
Coating	Protected silver
Hysteresis	20 %

4) Control System

Four computer systems are used for the LGS/AO188 control. One real time computer for closed loop (RTS), one host computer (ICS), one data handling computer for diagnostics, data storage and auto control parameter tuning (DHS), and a laser control computer (LCS). For fast closed loop computation, a real time Linux computer manufactured by Concurrent Computer corp. is used. The computer has 4 Xeon CPUs with 2.0 GHz clock speed. The single CPU performs matrix calculation of 188x188 in 25~35 μsec which is fast enough for our control. All the computers are in the control building for better environment for the maintenance. D/A boards for DM drive and APD counter boards are installed at the Nasmyth focus, and they are connected with the computers through fast sFPDP optical fiber link with maximum data transfer speed of 2.125 Gbps.

5) Laser Guide Star System

The sum-frequency solid state laser generating 589 nm has been developed in collaboration with Megaopt Co, RIKEN, and NAOJ [7][8]. The average power of 4.5 W is achieved. The laser system is installed on the Nasmyth floor in a class10000 clean room. The beam transfer optical fiber is photonic crystal fiber with 35 m length. This fiber is a new concept optical fiber with many small holes around the core to effectively reduce the refractive index then the fiber has larger core diameter than conventional step-index optical fiber, which allows a reduction of power density in the fiber. The fiber core diameter (mode field diameter) is 14 μm and, we have confirmed that there is no Stimulated Brillouin Scattering (SBS) effect in our test with 200 m length fiber [9].

A laser transfer telescope (LLT) with 50 cm aperture will be mounted on the back side of the Subaru secondary mirror. The LLT and telescope interface is designed so that it can be easily mounted and dismounted because we share the focus with other prime focus instruments.

3. FIRST LIGHT OBSERVATION

We had the first light of the system on October of 2006. We have achieved Strehl ratio of 0.5 at K band under the 0.8 arcsec visible seeing condition. The spatial resolution was still high, 0.064 arcsec even at z band (1.03 μm). On visible monitor camera, the resolution was about 0.1 arcsec. It is encouraging to do science in visible wavelength with this AO system.

Laser projection on the sky was also successfully performed at the same observing run. We have not closed loop with the laser spot at this run.

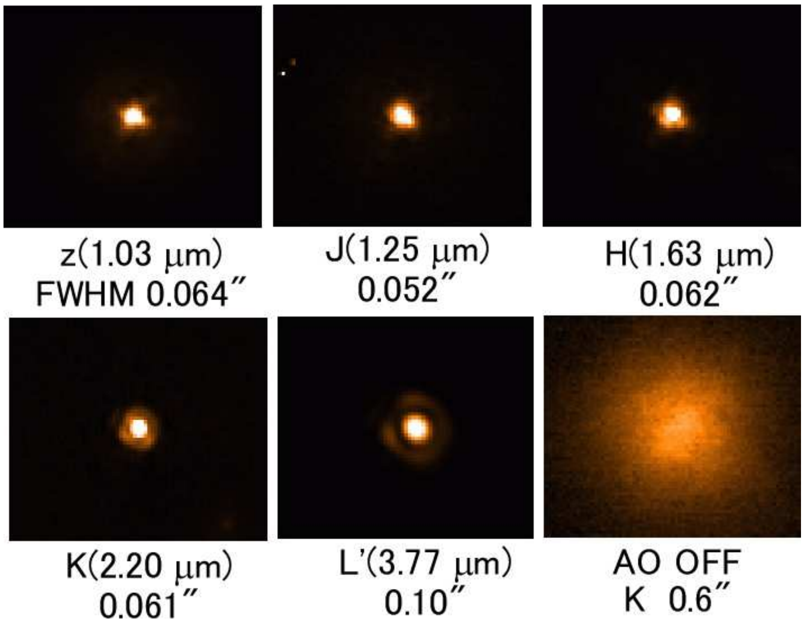

Fig. 6. Images corrected by AO188 at the first light.

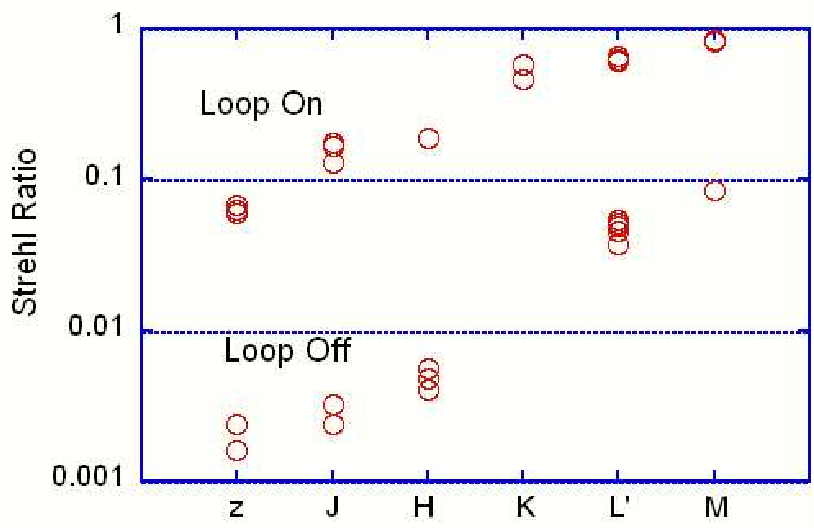

Fig. 7. Strehl ratio with and without AO correction at the first light.

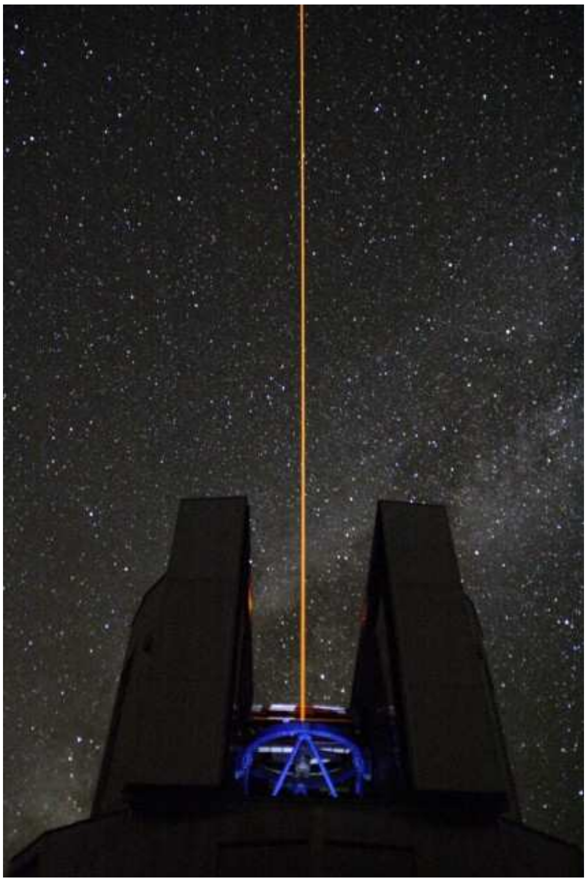
Fig. 8. Projected laser beam to the sky

4. INSTRUMENTS WITH AO188

Two instruments, IRCS and HiCIAO will be used with AO188. The IRCS has been used for Cassegrain AO system. The mounting structure is modified for Nasmyth platform. Modified IRCS uses 1024x1024 InSb array with 12, 18, 47mas/pix at Nasmyth focus. It has spectroscopic mode of Grism (R=1000) and Echell (R<20000). A low dispersion and wide spectral coverage spectroscopic mode (1.5~5 μm simultaneously, R=100 @3 μm) is added at this modification [10].

HiCIAO is a new instrument for AO188 with 2048 x 2048 HgCdTe array [11]. The target is to find exoplanets with coronagraph and simultaneous differential imager (SDI) to obtain high contrast observation capability. Thanks to the flexibility of Nasmyth platform, we are able to add easily advanced coronagraph such as PIAA and extreme AO system between AO188 and HiCIAO in the near future [12]. Additionally, a visible integral field spectrograph by Kyoto University is also used with this AO system.

5. SCHEDULE

After the first light, we have been working to improve the system for common use observation. The schedule is as follows.

2008 Jan	Reassemble the optomechanics, laboratory experiment, closed loop test
2008 Jun	Install at the summit, start engineering run
2009 Jan	Common use start

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