

# Active and Adaptive Optics of the 8.2m Subaru Telescope and Future Large Telescopes

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*Abstract*— This paper describes the structure and the performance of the active optics to achieve the figure control of the 8.2m primary mirror of the Subaru Telescope and of the adaptive optics system for compensating the image deterioration due to the atmospheric turbulence. Also introduced are the upgrade plan of the Subaru adaptive optics system and various ideas and plans for constructing next generation 30m-100m ground based telescopes.

*Keywords*— Astronomy, Adaptive Optics, Active Optics, Subaru Telescope

## I. INTRODUCTION

THE National Astronomical Observatory constructed the Subaru Telescope [1] for optical and infrared astronomy atop Mauna Kea, Hawaii island at 4137m from the sea level (Figure 1). The construction took 9 years starting from 1991 and the first light images proved its high quality for astronomical observations [2]. It is now offered together with its suite of 7 scientific instruments to the astronomers community of the world in regular basis.

The updated information on the Subaru Telescope can be found at the following home page:

<http://subarutelescope.org/index.html>

## II. ACTIVE SUPPORT OF THE 8.2M SUBARU PRIMARY MIRROR

The primary mirror of the Subaru Telescope, made of Corning <sup>TM</sup>ULE glass, has a physical diameter of 8.3m and a thickness of 20cm. It has a meniscus shape with an approximate radius of curvature of 30m and weighs 23 metric ton. The surface shape of the mirror should be maintained to the prescribed figure with a figure error less than 30nm rms.

To achieve this accuracy, the primary mirror is supported by 261 electro-mechanical actuators inserted in the pockets drilled from the back surface of the mirror (Figure 2)[3]. The supporting actuators (Figure 3) are distributed evenly along eight rings so that the supporting force becomes more or less constant. The actual support points of each actuator are aligned to lie on the central surface of local gravity of the mirror and this arrangement ensured local passive support of the mirror by the lever and counter balance structure of each actuator along the direction orthogonal to the optical axis when the mirror is tilted to track the observing target.

The support force distribution is pre calculated based on the finite element analysis of the primary mirror support system [4] and calibrated occasionally using the Shack-

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Fig. 1. Enclosure of the 8.2m Subaru Telescope at the summit of Mauna Kea, Hawaii.

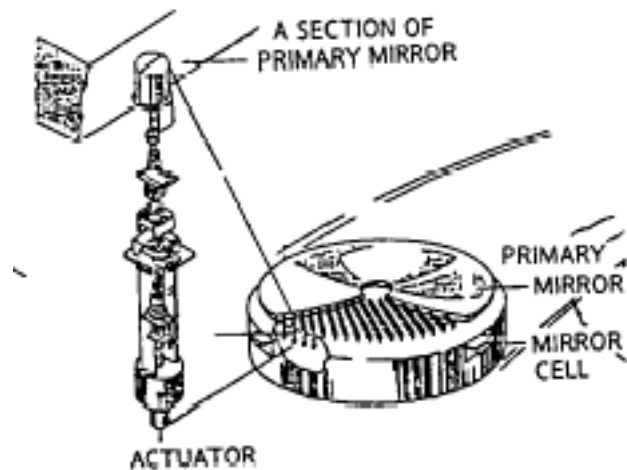


Fig. 2. The structure of the electromechanical actuator to support the primary mirror. The supporting force is measured by an accurate force sensor that monitors the frequency modulation due to the strain exerted at the actuator.

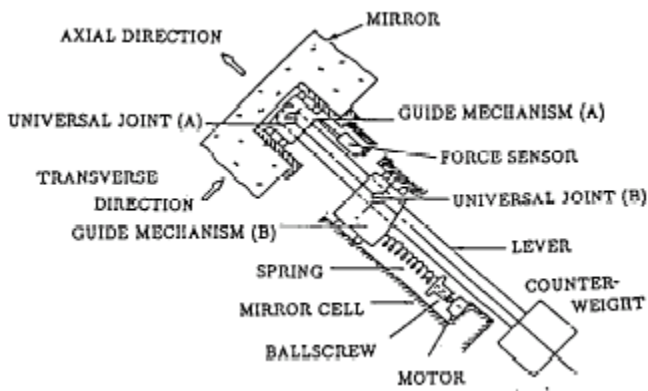


Fig. 3. The structure of the electromechanical actuator to support the primary mirror. The supporting force is measured by an accurate force sensor that monitors the frequency modulation due to the strain exerted at the actuator.

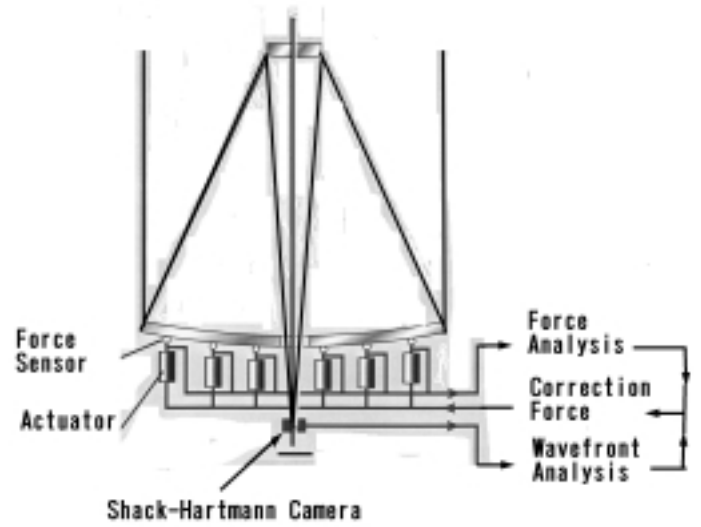


Fig. 5. The principle of the active optics of the 8.2m Subaru Telescope. The surface figure of the primary mirror is maintained by servo controlling the support force distribution, which is calibrated by optical wave front measurement.

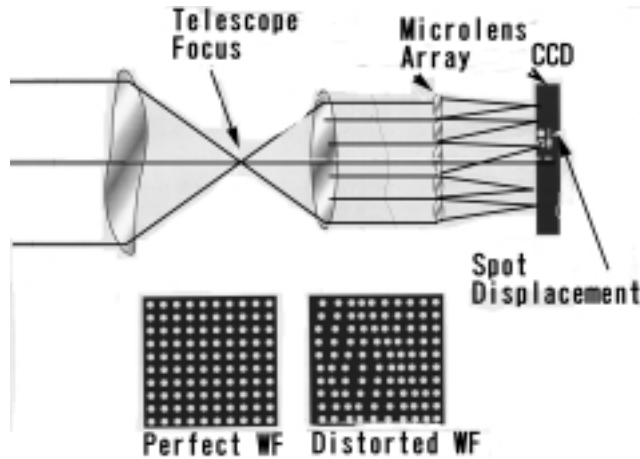


Fig. 4. The displacement of multiple images of a bright star produced by a micro lens array provides the surface figure error distribution.

Hartmann camera [5], an optical device to measure the accurate shape of the mirror surface by monitoring the displacement of about 300 spot images of a star produced by a micro lens array that maps the primary mirror surface (Figure 4).

The servo loop control system (Figure 5), taking the force error signal and the necessary correction of the look-up table caused, for instance, by the variation of temperature, achieves maintaining the surface figure of the primary mirror to the required accuracy (Figure 6).

### III. SUBARU ADAPTIVE OPTICS SYSTEM AND A PLAN FOR ITS UPGRADE

The Cassegrain Adaptive Optics System (Figure 7) of the Subaru Telescope has a curvature wave front sensor with 36 avalanche photon counting diodes and a bimorph piezoelectric deformable mirror (Figure 8) with 36 matched electrodes. The principle of the system is shown conceptually in Figure 9 [6]. The system is optimized for  $2.2 \mu\text{m}$  K-band and can be driven with a guide star as faint as  $R=19$ . The FWHM of the corrected image at K-band is 0.07 arc



Fig. 6. The polished 8.2m primary mirror at final acceptance test. The invar sleeves attached at the pockets drilled in the back surface for placing the actuators are visible through the transparent glass.

sec corresponding to the diffraction limit of 8.2m telescope and the attained Strehl ratio is as high as 0.4 for bright guiding stars.

Figure 10 shows an example image of a binary star system obtained with and without the Subaru Adaptive Optics system.

An upgrade plan to replace the present 36 element system to an 85 element system is about to start to give better performance with higher Strehl and lower scattered light in the outskirts of the point spread function. Another key element of the upgrade plan is to install a laser guide star system. A 2W laser tuned at NaD line will be used to produce a coherent beam relayed by an optical fiber to

Specification of Subaru Cassegrain AO system	
Spectral coverage	1 - 5 $\mu$ m for compensation 0.5 - 20 $\mu$ m for transmission
WFS	Curvature sensor with 36 photon counting APDs
Deformable mirror	Bimorph mirror with 36 control electrodes
Beam diameter	60 mm
Focal length	720 mm
Focal ratio	12.4
FOV	>2 arcmin. for coverage of optics; tip/tilt correction 1 arcmin. for higher order AO compensation
Control bandwidth	> 100 Hz (2.1 k corrections/sec)

Fig. 7. The specification of the Cassegrain adaptive optics system of the 8.2m Subaru Telescope.

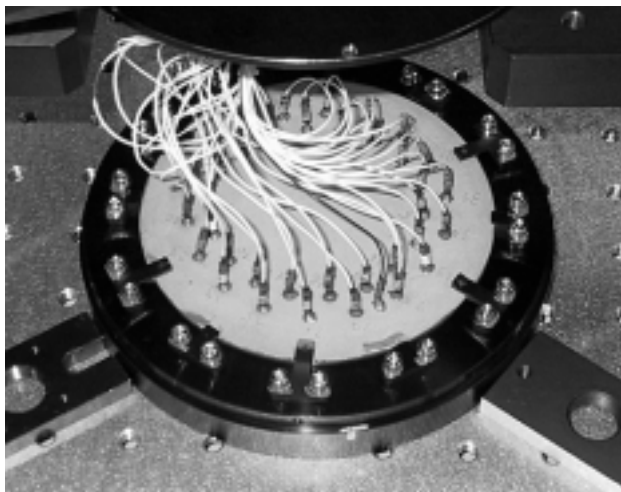


Fig. 8. The deformable mirror of the Subaru adaptive optics system.

the transmitting telescope mounted at the top end module of the Subaru Telescope. The transmitted beam will produce a sodium laser guide star in the upper atmosphere at about 90km in height bright enough to be used as the light source to measure the wavefront turbulence inherent below the 90km layer [7]. More details of the adaptive optics system of the Subaru Telescope can be found at :

<http://merope.mtk.nao.ac.jp/kamata/AdaptiveOptics/index.html>

#### IV. NEXT GENERATION EXTREMELY LARGE GROUND BASED TELESCOPES

Since quite a few 8-10m telescopes, including the Keck I and II, VLT1-4, Subaru, Gemini North and South, and the HET are successfully commissioned, serious feasibility studies to construct next generation ground based telescopes of diameter 30-100m are undertaken. Among others, the studies of 30m CELT, 100m OWL (Figure 11), and 50m GSMT have been made systematically. All these plans assumes segmented mirrors to compose a large aperture primary.

Research and development of the advanced adaptive optics system for realizing the diffraction limited imaging over

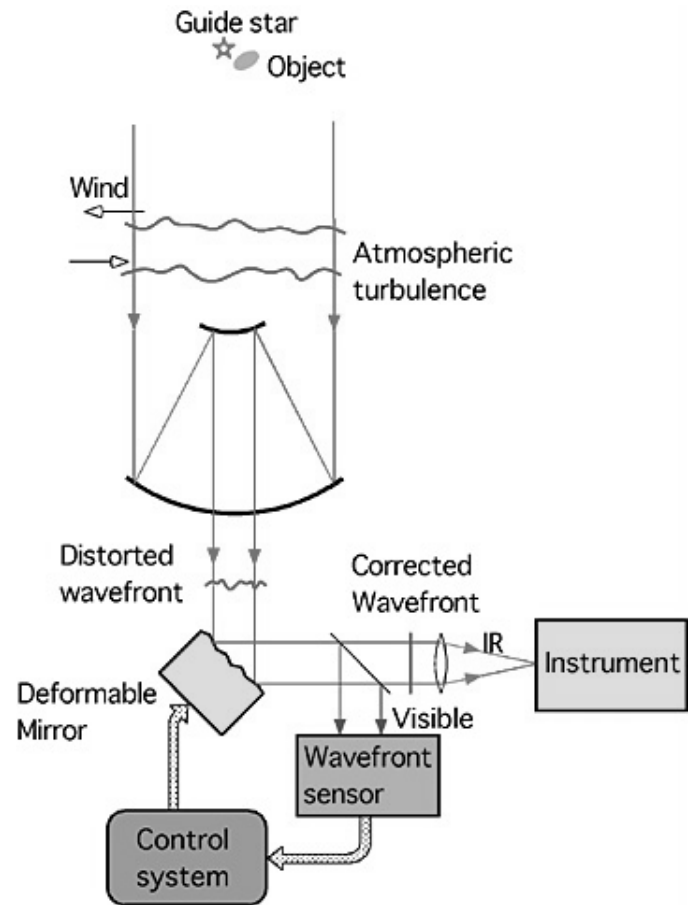


Fig. 9. The adaptive optics of the 8.2m Subaru Telescope.

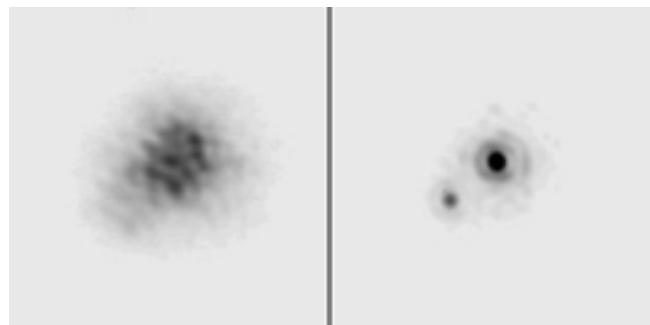


Fig. 10. A binary star imaged with (right) and without (left) the adaptive optics of the 8.2m Subaru Telescope.

a fairly wide field of view is essential. The present paper summarizes the current status of these feasibility studies made among various groups of experienced astronomers and engineers. More information can be seen, for instance, at:

<http://celt.ucolick.org/>  
<http://www.eso.org/projects/owl/>

#### ACKNOWLEDGMENTS

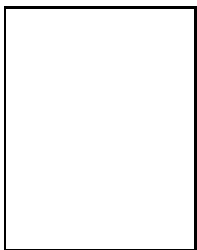
The author would like to acknowledge all the people working for establishing the active and adaptive optics systems of the Subaru Telescope.



Fig. 11. A concept of the 100m overwhelmingly large telescope plan studied at ESO.

#### REFERENCES

- [1] Iye,M.: *Japan 8m Telescope : Subaru Project*, Proc. 7th IAU Regional Meeting, J.Korean Astron.Soc., Vol.29, Suppl. pp371-374, (1997)
- [2] Iye, M., Iwamuro,F., Maihara,T., et al. *Subaru first-light deep photometry of galaxies in A851 field*, PASJ, 52, 9-24, (2000)
- [3] M.Iye and K.Kodaira, *Primary mirror support system for the SUBARU Telescope*, SPIE Proc.2199, pp.762-772, (1994/7)
- [4] Iye,M., Noguchi,T., Torii,Y., Mikami,Y., Yamashita,Y., Tanaka,W., Tabata,M., and N.Itoh, *Active Optics Experiments with a 62cm Thin Mirror*, in Advanced Technology Optical Telescopes W, SPIE Proc., 1236, 929-939, (1990)
- [5] Noguchi,T., Iye,M., Kawakami,H., Nakagiri,M., Norimoto,Y., Oshima,,N., Shibasaki,H., Tanaka,W., Torii,Y., and Yamashita,Y., *Active Optics Experiments I. : Shack-Hartmann Wave-Front Analyzer to Measure F/5 Mirrors*, Publ.Natl.Astron.Obs.Japan, Vol.1, p.49-55, (1989)
- [6] Takami,H., Takato,N., Otsubo,M., Kanzawa,T., Kamata, Y., Nakashima,K., and Iye, M., *Adaptive Optics system for Cassegrain focus of Subaru 8.2m telescope*, SPIE 3353, 500-(1998)
- [7] Hayano,Y., Takami,H., Takato,N., Kanzawa,T., Kamata,Y., Nakashima,K., Iye,M., and Oya,S.: *Preliminary experiments of prototype laser guide star system for Subaru Telescope*, in Adaptive Optical Systems Technology, ed.P.Wizinowich, SPIE 4007, 149-154, (2000)



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**Waikoloa (2002) on astronomical instrumentation.**