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Ground-layer turbulence evaluation project at Subaru Telescope

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Abstract. A candidate of the next-generation adaptive optics (AO) system at Subaru Telescope is a ground-layer AO (GLAO) using an adaptive secondary mirror. The performance of GLAO depends on the turbulence profile because only ground-layer turbulence is corrected. At Mouna Kea, the profile data have been obtained at the summit ridge site and TMT site. However, the height difference of the Subaru site from these sites is about 100 m, close to the scale height of the ground-layer turbulence. There is a possibility that the topographical difference affects the ground-layer turbulence property, and then the performance of GLAO. In this paper, the activity to evaluate the ground-layer turbulence at the Subaru site is introduced.

1. Introduction

A plan for the next infrared instrument with improved spatial-resolution by use of adaptive optics (AO), is on discussion at Subaru Telescope [1]. The instrument will be installed at Cassegrain focus, because the current infrared instrument with AO (LGSAO188) has been completed commissioning and in open-use operation at Nasmyth focus. A candidate is a wide-field (10' or more) camera-and-spectrograph with a ground-layer AO (GLAO) using an adaptive secondary mirror, called ULTIMATE-SUBARU as the project name (Hayano et al. 2014 [1]). The wide-field infrared instrument will be a natural upgrade of current seeing-limited instrument, Multi-Object Infrared Camera and Spectrograph (MOIRCS), and also has a good synergy with seeing-limited optical wide-filed instruments of Subaru, Hyper Suprime Cam (HSC; commissioned) or Prime Focus Spectrograph (PFS; on-going project) used in dark nights. Also the capability of the infrared wide-field instrument will be complement of the Thirty-Meter-Telescope (TMT) at Mauna Kea. Studies have been done for the ULTIMATE-SUBARU project on technical feasibility, performance estimation by simulation, science cases and the instrument, the budget plan and time-line, and so on. According to the preliminary simulation (Oya et al.2012 [2], 2014 [3]), the expected performance of full-width at the half maximum (FWHM) is 0.2 arcsec in the K-band over 10 arcminute of the field of view. under moderate seeing condition. However, the result of performance simulation depends much on the seeing condition at the telescope. This is why the seeing evaluation at the Subaru Telescope is needed.

[1] http://www.naoj.org/

2. Impact of ground-layer turbulence on GLAO performance

GLAO realizes the widest working field-of-view (FoV) by correcting only the ground-layer turbulence, which is common for objects over wide FoV (Fig.1). The aimed performance is improvement of the seeing rather than the diffraction-limit, because the turbulence in the upper free-atmosphere is not corrected. The performance is determined by the uncorrected turbulence in the upper free atmosphere and affected by the turbulence profile. Interestingly, GLAO performance changes by the height distribution of turbulence even with the same integrated strength (r_0) of the turbulence (Gemini Ground Layer Adaptive Optics Feasibility Study Report, Appendix F1; Oya et al. 2012 [2]). Thus, it is quite important to know how much of the turbulence is attributed to the ground-layer.

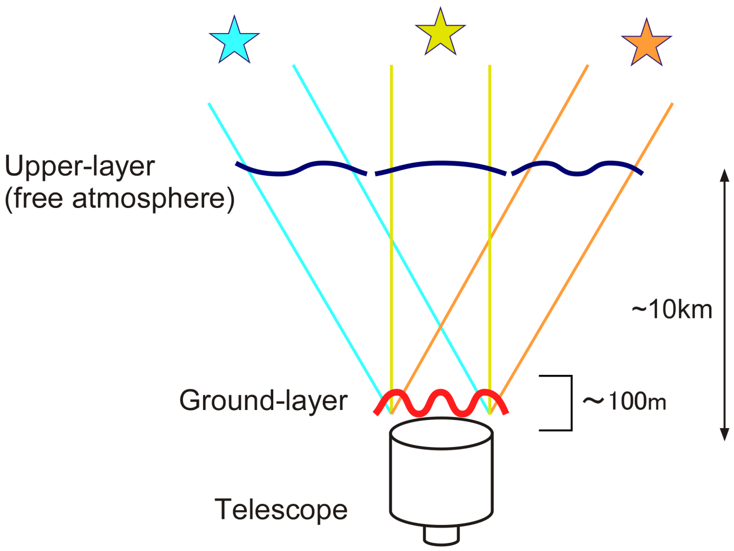

Figure 1. Schematic diagram explaining the principle of GLAO

3. Preceding campaigns at Mauna Kea

3.1. Mauna Kea Ridge

The campaign was done by Chun et al. 2009 [4] over 18 month from October, 2006 to July 2008. Two optical turbulence profilers using double star were used for the measurement. SLODAR (SLOpe-Detection And Ranging) detects the the turbulence height by spatial cross-correlation between the centroids measured by Shack-Hartmann WFS subapertures and obtains data up to 640 m with 80 m bins. LOLAS (LOw-Layer Scintillation Detection and Ranging) determines the turbulence height by calculating the spatial auto-correlation between scintillation pattern generated by double star and obtains data up to 60 m by 15 m bins. In the SLODAR results, the most of the turbulence is concentrated in the first 80 m bin and the LOLAS reveals that all of the turbulence is below 60 m and most of time below 30m.

3.2. TMT site, 13N

The campaign was done by Els et al. 2009 [5] from Jun, 2005 to February, 2008 as a part of TMT site testing for five candidate sites. One optical profiler and one sonic profiler have been used for the measurement. MASS-DIMM (Multi-Aperture Scintillation Sensor - DIfferential Motion Monitor) consists of two optical detectors. DIMM measures the integrated total strength of the turbulence (r_0). MASS determines the height profile at 0.5, 1, 2, 4, 8, 16 km, by spatial auto-correlation of scintillation at different separation. The ground-layer (0 m) strength is subtracting the sum of the upper layer strength measured by MASS from the total strength by DIMM. SODAR (SOund Detection And Ranging) is a sonic profiler which measures the

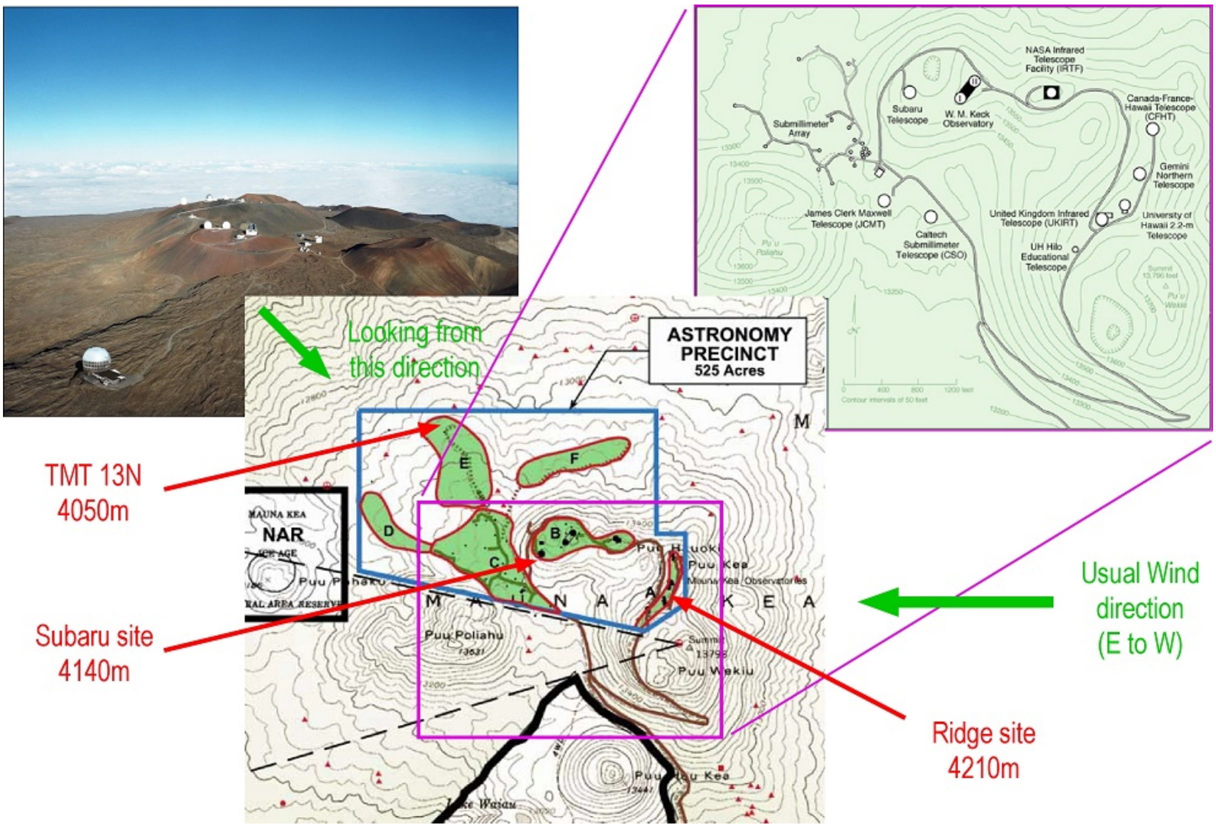

Figure 2. The topography of the Mauna Kea summit. The upper-left panel is an aerial photograph looking the summit from the north-west. The computer graphics of TMT is synthesized at 13N location (lower-left corner in the photograph). The location of the ridge site and 13N relative to the Subaru site is displayed in the lower-middle panle. The upper-right panel is the close-up of the area for major observatories, including Subaru site and the ridge site. The original source of the upper-left panel is IfA web site (http://www.ifa.hawaii.edu) and the others are from TMT web site (http://www.tmt.org).

turbulence from 10 m to 200 m with 5 m resolution and is used between October, 2005 to December, 2007 The MASS-DIMM data show that the turbulence is well concentrated at the ground and SODAR data indicate about half of the seeing is dominated by the first 100m.

3.3. Topographical difference of Subaru site

The data obtained by previous works indicate the ground-layer is concentrated below 100 m. However, the elevation of these site-testing locations is different from Subaru about 100 m. Moreover the local terrain is not smooth due to cinder-cone structure (Fig.2). The wind predominantly blows from the east. The Subaru site is on the leeward side of the ridge site and at the lower elevation. The behavior of the ground-layer turbulence after blowing over the ridge is not clear, if it blows down along the surface and keeps laminar flow or blows off at the ridge and goes rather horizontally. The ground-layer turbulence height at the Subaru site is also expected to be below 100m in the former case, while the height will be around 200m due to the elevation difference in the latter case. Therefore, the local measurement of the ground-layer turbulence at Subaru site is necessary, in addition to the preceding campaigns at other sites of the Mauna Kea.

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4. Activity at Subaru Telescope

To evaluate the local ground-layer turbulence at the Subaru site, two profilers (one optical and one sonic) have been introduced. Additionally, the actual correction by GLAO mode through the telescope has been tested, which indicates the performance of GLAO at the Subaru telescope is promising as expected by the simulations.

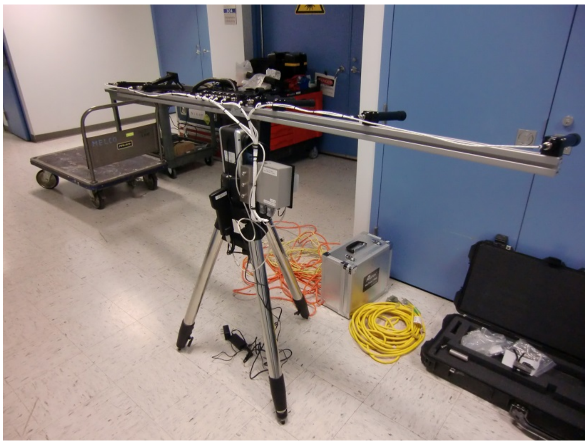

Figure 3. Portable turbulence profiler 2 (PTP2)

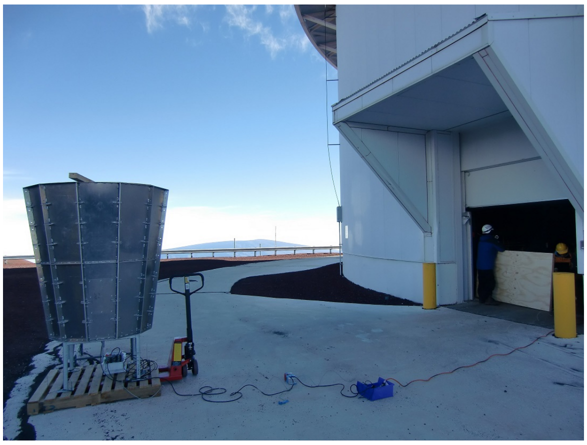

Figure 4. Surface layer NOn-Doppler Acoustic Radar (SNODAR)

4.1. PTP2

PTP2 (Portable Turbulence Profiler 2) is a mobile type of lunar scintillometers developed at University of British-Columbia (e.g., Hickson et al. 2013 [6]). PTP2 has twelve photodiodes (PDs) placed at various separation on a horizontal bar (Fig.3). A PD detects the scintillation of the entire moon. The height of the turbulence is determined by correlation calculation between PDs with different baselines. The height resolution is high at ground-layer and detectable height ranges up to several hundreds; hence, suitable for ground-layer measurement. The initial test has been finished and detection of lunar scintillation has been confirmed. After improving the tracking of the moon and reducing 60 Hz noise on PDs, data accumulation will be started on regular basis.

4.2. SNODAR

SNODAR (Surface layer NOn-Doppler Acoustic Radar) is developed at University of New South-Wale (e.g., Bonner et al. 2010 [7]) and used for boundary layer evaluation in Antarctica. SNODAR has quite high resolution (1 m at best) up to 100 m. An advantage of sonic profiler is that measurement is possible even in day time or cloudy night. A standard type sonic profiler, SODAR, had been introduced once at the Subaru site, but did not work properly due to the acoustic noise from the ventilator fan of the Keck Telescope. In addition to the use of single frequency, SNODAR has a large sound cone (Fig.4) which is effective to successfully reduce the influence of the acoustic noise. Figure 5 displays a quick result for a night obtained during the initial test in July, 2014. The result indicates that the thickness of the boundary layer is less than 50m also at the Subaru Telescope. Although this is only a result for a night, it is quite encouraging for the GLAO activity at the Subaru Telescope. Further long-term monitoring under various weather condition is desired and will be started after installation of SNODAR on the roof of the control building.

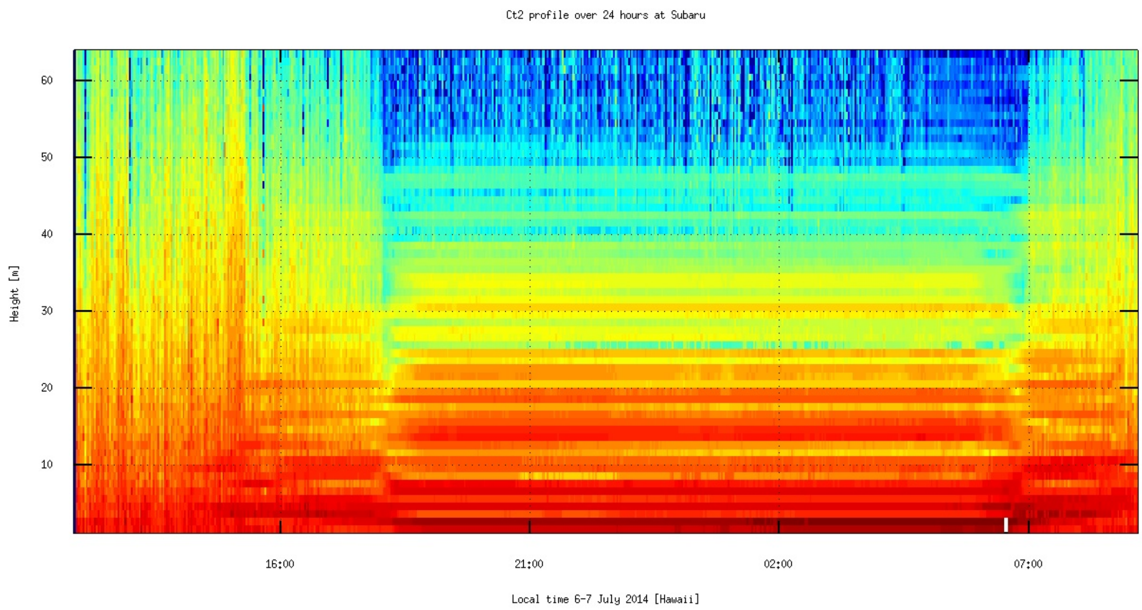

Figure 5. An example of SNODAR result obtained during initial test (by courtesy of Colin Bonner).

4.3. GLAO correction by RAVEN

RAVEN is an MOAO (Multi-Object Adaptive Optics) demonstrator developed at University of Victoria and carried-in to the Subaru Telescope (Lardière et al. 2014 [8]). RAVEN also works in an open-loop GLAO mode. During the first engineering run in 2014, better correction than 0.13" has been achieved in the H-band under good seeing condition (0.32"). In Fig.6, the quick

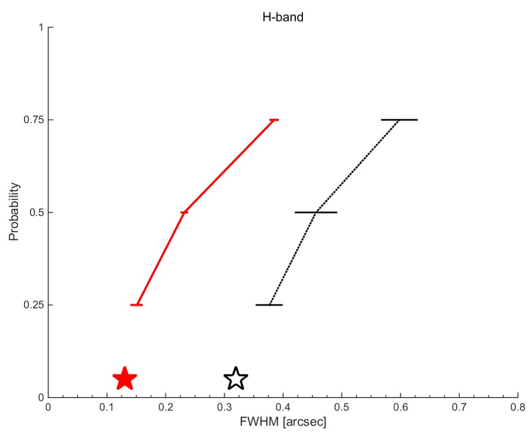

Figure 6. A quick result of GLAO mode obtained during the first engineering run by RAVENN, is overplotted on GLAO simulation for ULTIMATE-SUBARU.

result obtained during the first engineering run is overplotted on the expected performance of Subaru GLAO system (ULTIMATE-Subaru; Oya et al. 2012 [2], 2014 [3]) in the H-band. The observed value by RAVEN is in fairly good agreement with the expected performance, even with the difference of detailed system configuration from ULTIMATE-SUBARU (e.g., open-loop operation and narrower GS configuration in the RAVEN case). This is probably because, once the ground layer is corrected enough, the image size of GLAO is determined by the rest of uncorrected turbulence in the upper free-atmosphere regardless of the details of the system.

4.4. Summary
A ground-layer turbulence evaluation project is on-going at the Subaru Telescope. An optical profiler, PTP2, and a sonic profiler, SNODAR, have been introduced. Initial tests for both of the profilers have been finished. Especially, the quick result by SNODAR indicates the ground layer is below 50m, which is encouraging for GLAO plan at the Subaru Telescope. The actual GLAO corrected image through the telescope obtained by the open-loop GLAO mode of RAVEN, shows better FWHM size than 0.2" as expected by GLAO simulations.

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