Consideration of geometric albedo observation using the laser altimeter on the Hayabusa-2 spacecraft

（はやぶさ 2 搭載レーザー高度計によるアルベド観測検討）

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ABSTRACT

The Hayabusa-2 spacecraft is launched at end of 2014 to explore C-type asteroid 1999JU3. We have a plan to investigate the geometric albedo of 1999JU3 using the laser altimeter (LIDAR) boarded on Hayabusa-2. The Hayabusa-2 LIDAR has a function to measure intensities of the sending and receiving laser pulses. We can estimate the geometric albedo of the asteroid surface at laser wavelength (1064nm) using the laser intensity data, and construct a geometric albedo map so as to investigate variation of the albedo related with topography and geological condition such as space weathering.

To derive the geometric albedo from the intensity data of the laser pulse, we have to investigate the characteristics of the laser transmitter and receiver of the LIDAR. Firstly, we have investigated the characteristic of the laser transmitter to convert observed intensity (digital value) of the sending laser into energy of the laser sending to the asteroid surface in the thermal vacuum test for the LIDAR flight model. Then, we have also investigated the relation (characteristics of the receiver) between energy of the laser pulse input into the LIDAR and the observed digital value representing intensity of the receiving laser. The ratio of the sending laser energy input into view of the LIDAR receiver was also measured in the thermal vacuum test to estimate accurate value of the geometric albedo.

The asteroid surface slope and roughness can change the observed intensity of the receiving laser pulse because the slope and roughness change the shape of the receiving laser pulse. In this study, we simulated how much the value of the observed intensity varies related with surface slope and altitude of spacecraft, and it is used to correct the intensity so as to remove effect of the surface slope. The error of the correction will be larger with larger slope and higher altitude.

Finally, we have evaluated accuracy of the geometric albedo derived from the data observed by the LIDAR based on measured errors of the characteristics of the LIDAR and that of correction of effect of the surface slope. If we assume observation at home position (altitude of 20km), we will be able to estimate the geometric albedo with 12-22% errors depending on degree of the surface slope. The error of albedo will be reduced by the data stacking on the area where the footprints overlap. The more validation of characteristic of the LIDAR receiver and more studies about effects of surface slope and roughness are required to derive the geometric albedo more accurately from the Hayabusa-2 LIDAR data.

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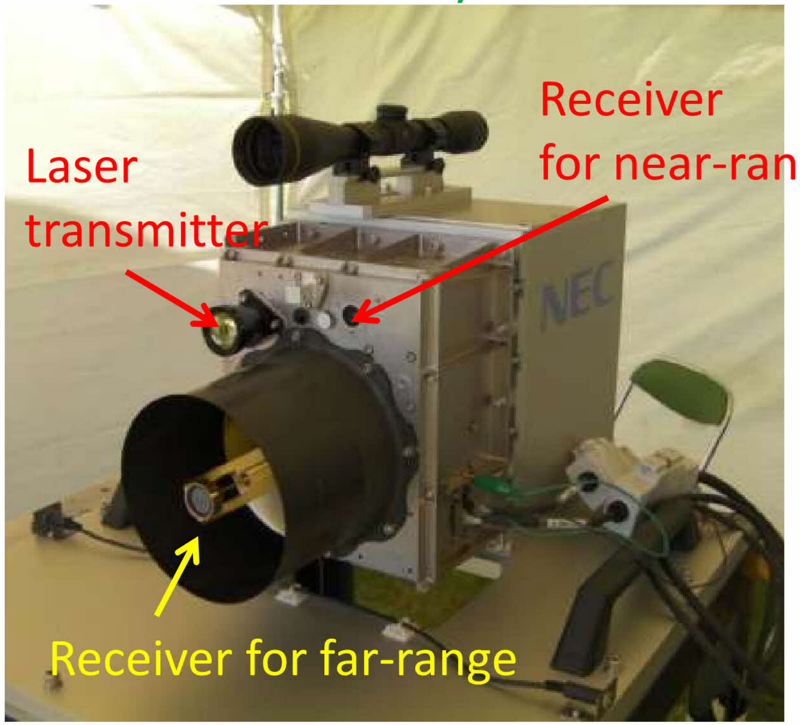
Hayabusa-2 LIDAR（Laser Altimeter）

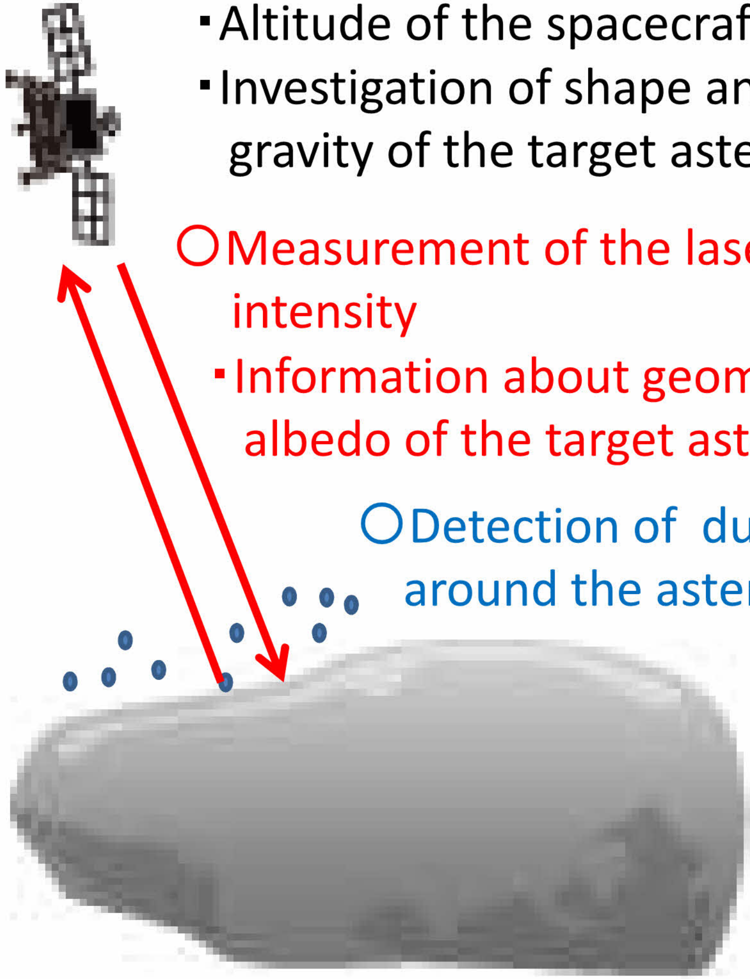
External view of Hayabusa-2 LIDAR



Specification of the Hayabusa-2 LIDAR

Ranging range：30m～over 25km
Resolution：0.5m
Sampling rate：1Hz
Laser wavelength：1064nm

Function of the Hayabusa-2 LIDAR



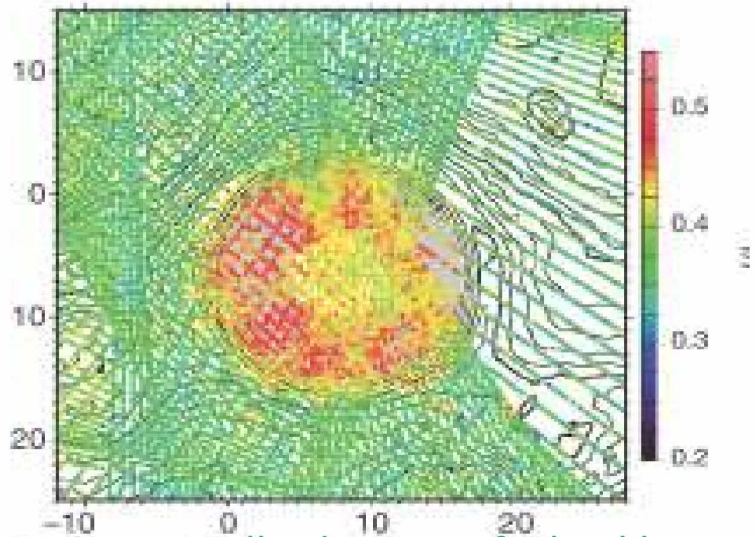
○Ranging
- Altitude of the spacecraft
- Investigation of shape and gravity of the target asteroid

○Measurement of the laser intensity
- Information about geometric albedo of the target asteroid

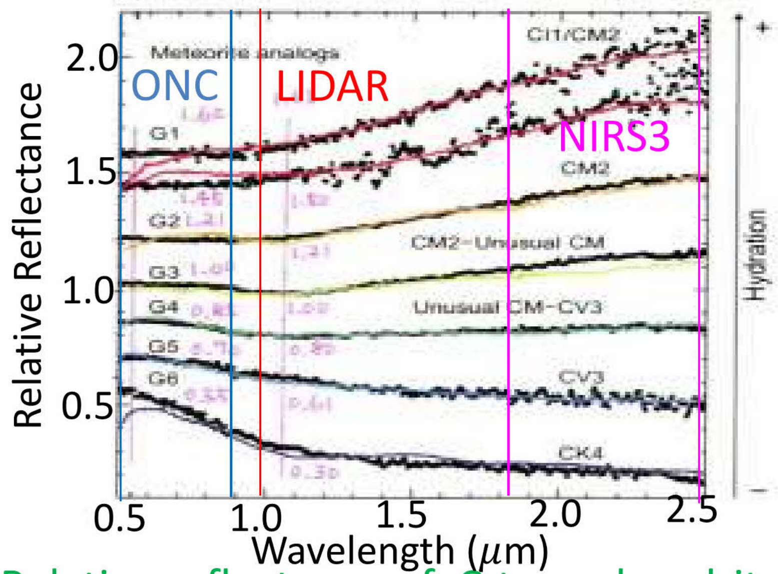
○Detection of dust around the asteroid

The target asteroid is C-type: 1999JU3 on Hayabusa-2 mission

Scientific target for albedo observation using the LIDAR



Geometric albedo map of Shackleton crater (Zuber et al., 2012)



Relative reflectance of C-type chondrite depending of water degree(Léon et al.,2012)

Measurement of intensities of the sending laser and receiving laser pulses with 1Hz sampling

Construction of geometric albedo map of 1999JU3 at laser wavelength (1064nm)

Relation with surface topography and geological condition

- With other instruments data

○Mineral composition and type of meteoroid

○Metamorphic grade by water

○Surface variation affected by space weathering and attachment of other asteroid materials

Derivation of Geometric Albedo Value from the LIDAR data

$$\rho = \frac{V_r}{V_p}\frac{\pi R^2}{SR * RR * \varepsilon} * S(\theta) * D(\delta)$$

ρ: Geometric albedo of the asteroid surface

R: Distance between the asteroid and the spacecraft (m)

Data obtained from observation by LIDAR

V_r: Intensity of receiving laser pulse (DU) V_p: Intensity of sending laser pulse (DU)

Characteristics of the receiver and the transmitter of the LIDAR

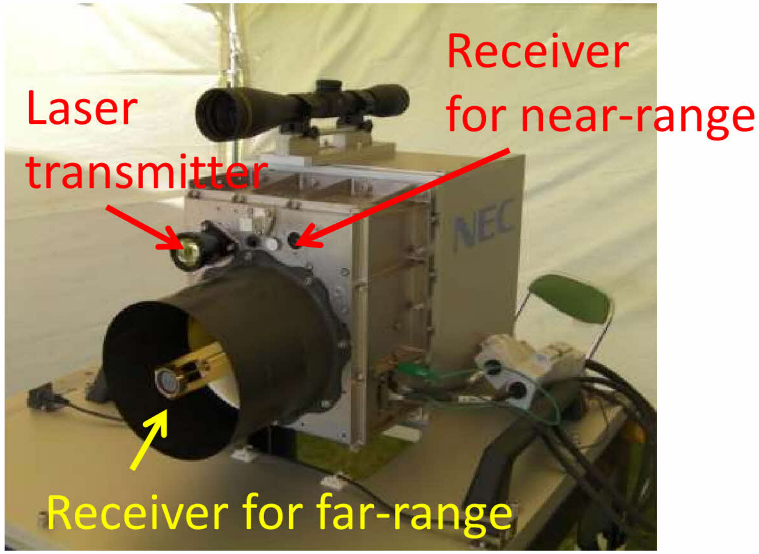
SR: Response of the laser transmitter (W/DU)
RR: Response of the laser receiver (DU/W)
ε: Utilization ratio of laser energy

Characteristic of the asteroid surface

S(θ): Correction term for intensity of receiving laser affected by surface slope θ
D(δ): Correction term for intensity of receiving laser affected by surface roughness δ

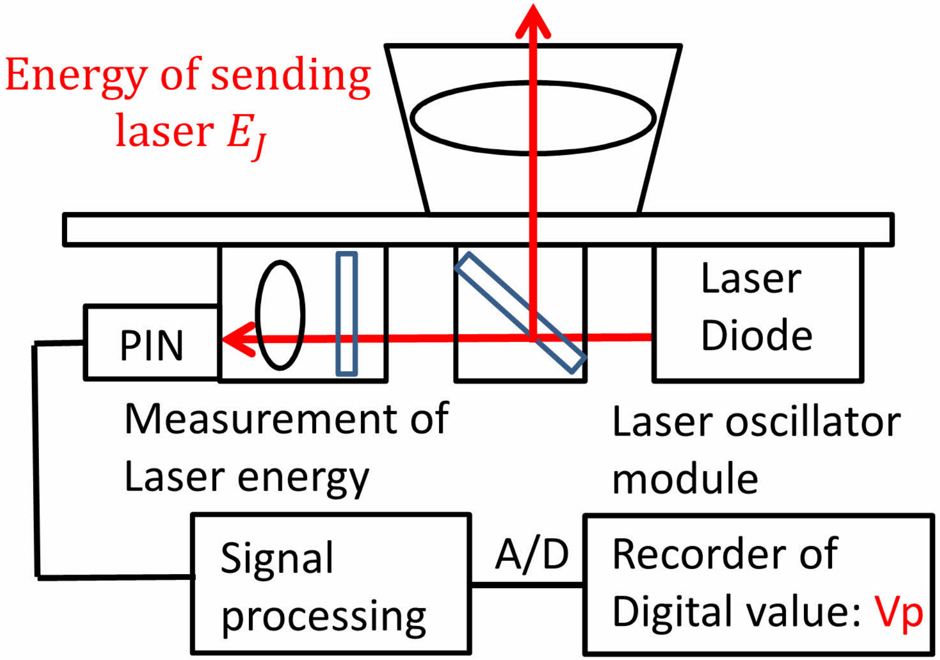
We measured SR, RR, ε of the LIDAR flight model and calculated S(θ) required to derive the geometric albedo, and then evaluated the accuracy of the value of geometric albedo derived from the LIDAR data.

Investigation of Response of the LIDAR Transmitter



We evaluated SR to derive energy of sending laser E_J from intensity of sending laser V_p (measured digital value)

○LIDAR-FM thermal vacuum test



Block diagram of the LIDAR laser transmitter

We simultaneously measured

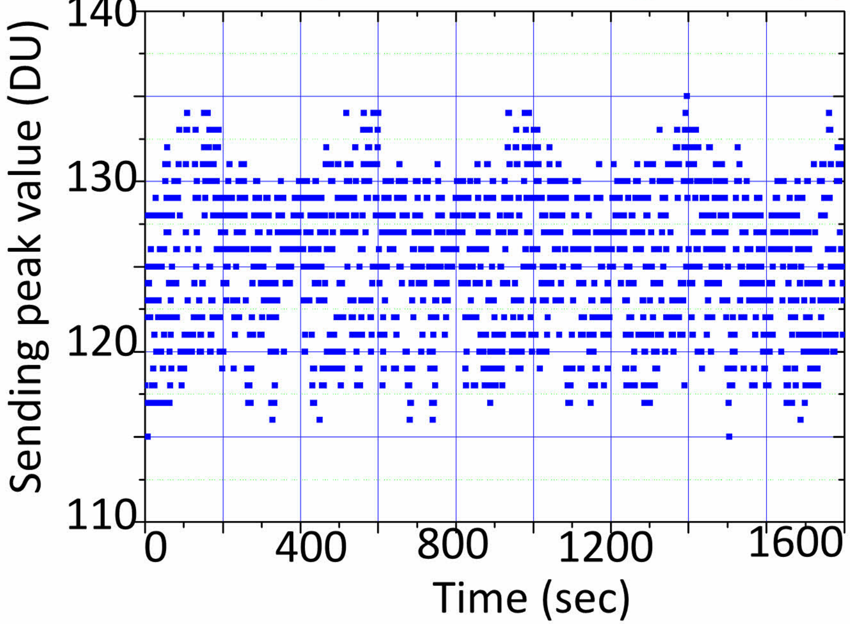
- Intensity of sending laser V_p
- energy of sending laser E_J

under the expected temperature around the target asteroid

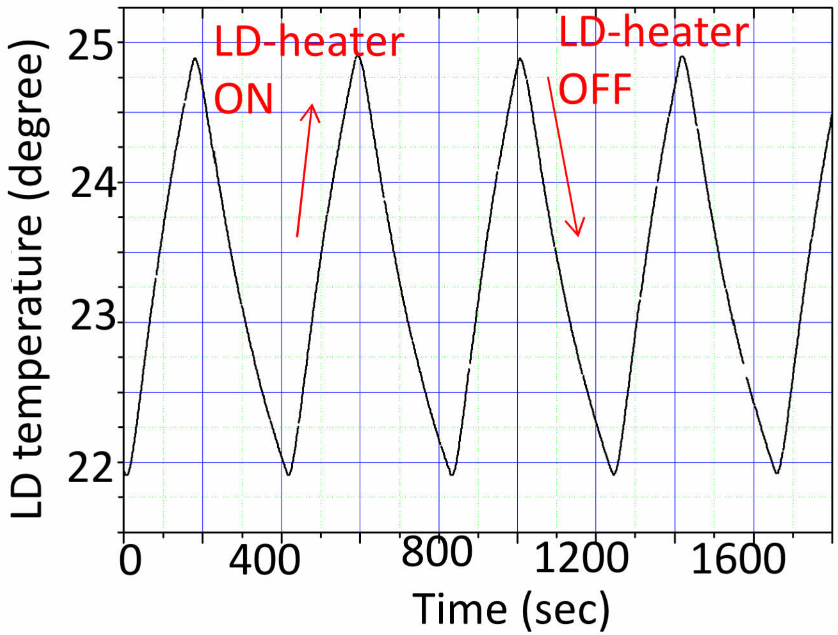
Relations between V_p and E_J under the expected temperature conditions.

Variations of Intensity and Energy of the Sending Laser

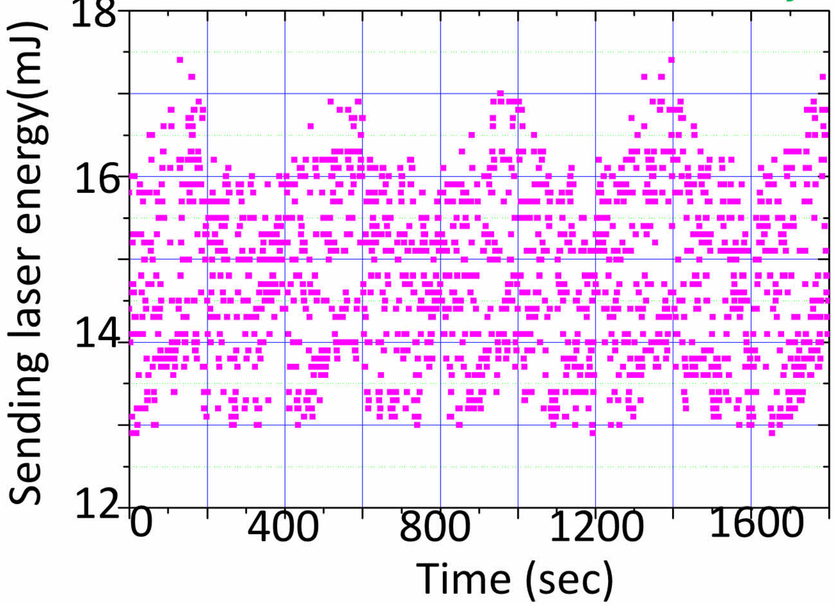
Intensity of the sending laser [Vp]



Temperature of the laser diode (LD)



Energy of the sending laser [E_J]

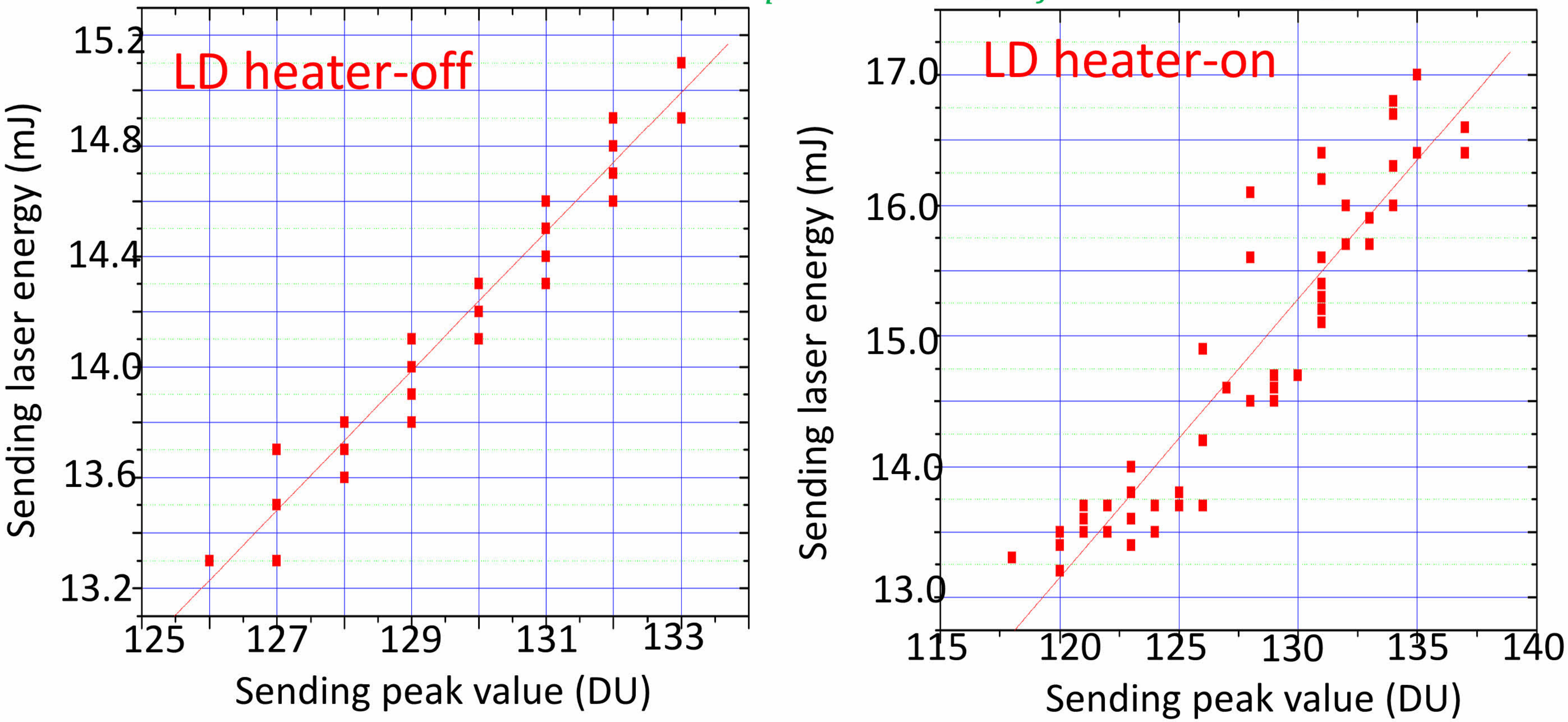


Under temperature expected in global mapping (GM) condition,

We found a correlation between intensity and energy of the sending laser, and their values vary depending on temperature of laser diode (Turning on and off of LD heater)

Derivation of Response of the Laser Transmitter

Relation between intensity V_p and energy E_J of the sending laser

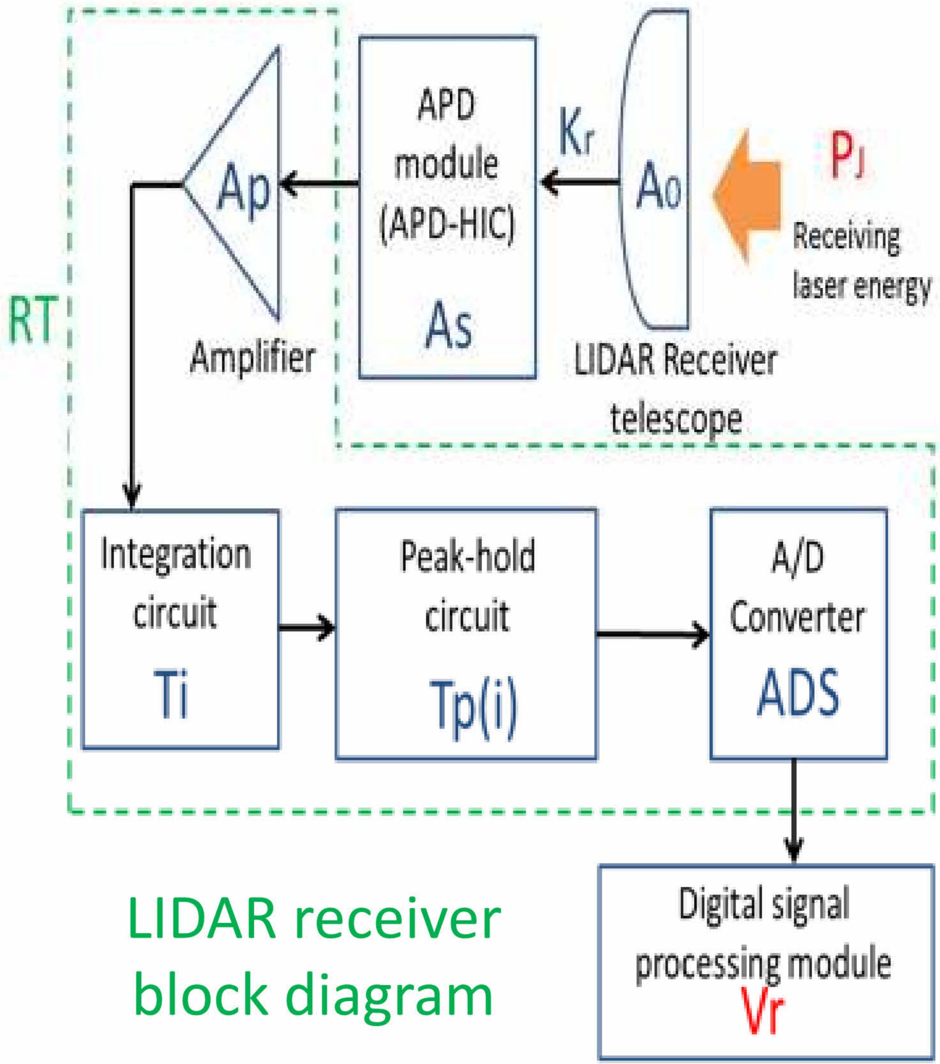


We found a linearity between intensity and energy of the sending laser
(The linearity is more stable when LD heater is turned off)

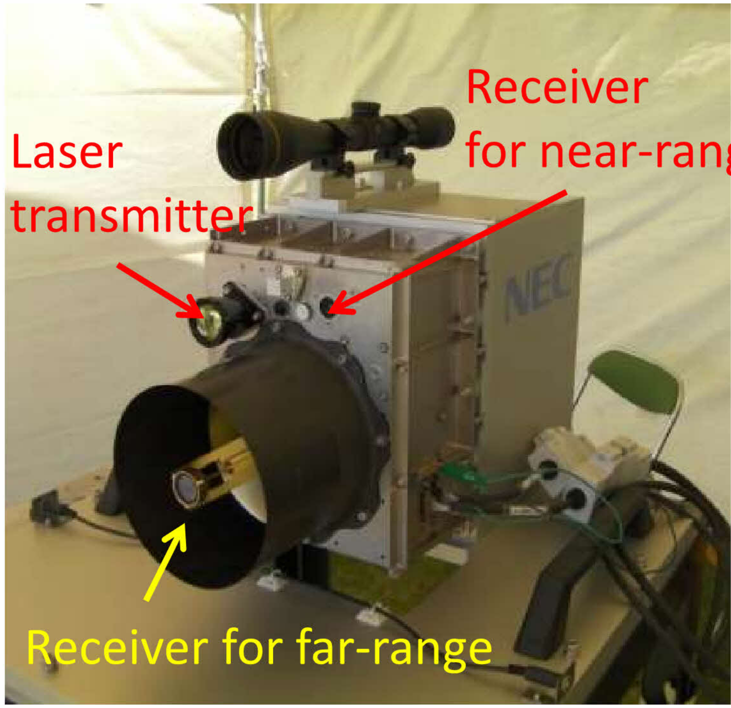
$$SR = {}^{E_J}\!/_{V_P} = 1.12094E-4 \pm 3.25188E-6\ (J/DU)$$

(The error is 2.90% when LD heater is turned off)

Investigation of Response of the LIDAR Receiver



LIDAR receiver
block diagram

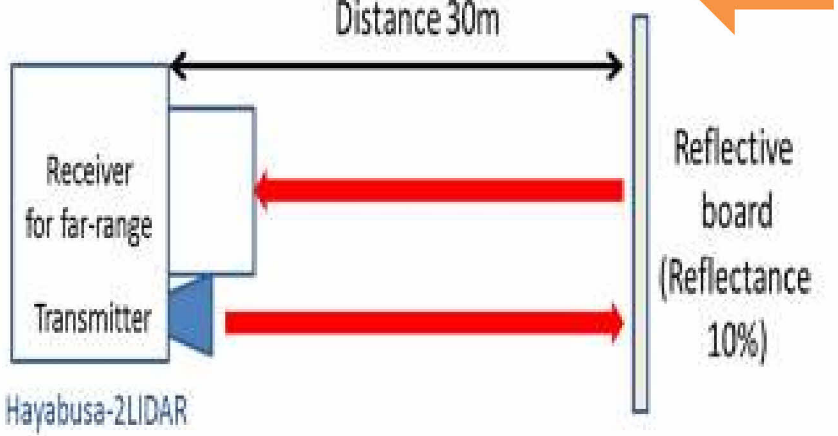


We evaluated RR to derive energy of the receiving laser P_J from the intensity of the laser V_r

$$RR = A_0 * K_r * A_S * RT$$

The gain of RR is controllable changing applied voltage to the APD.
We investigated Gain 1,2,4,8 of the RR used in an actual operation.

Experiment of LIDAR Laser Reflection



Sending of the laser with known energy from the transmitter

↓

Reflection at the reflected board with 10% reflectance

↓

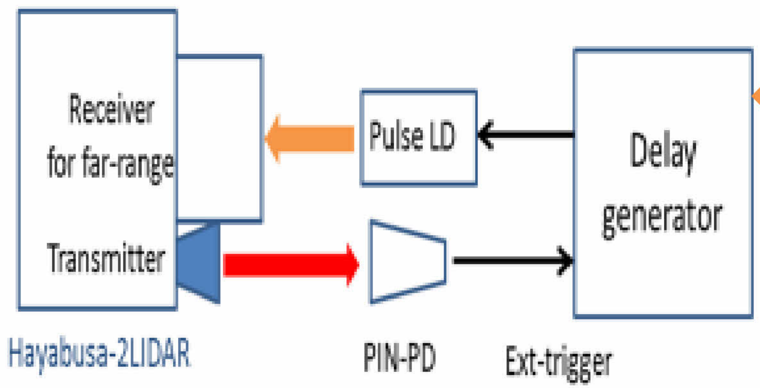
Derivation of RR with Gain 1 from the observed intensity V_r

↓

Estimation of the input laser energy from the pulse LD using the sensitivity of Gain1

↓

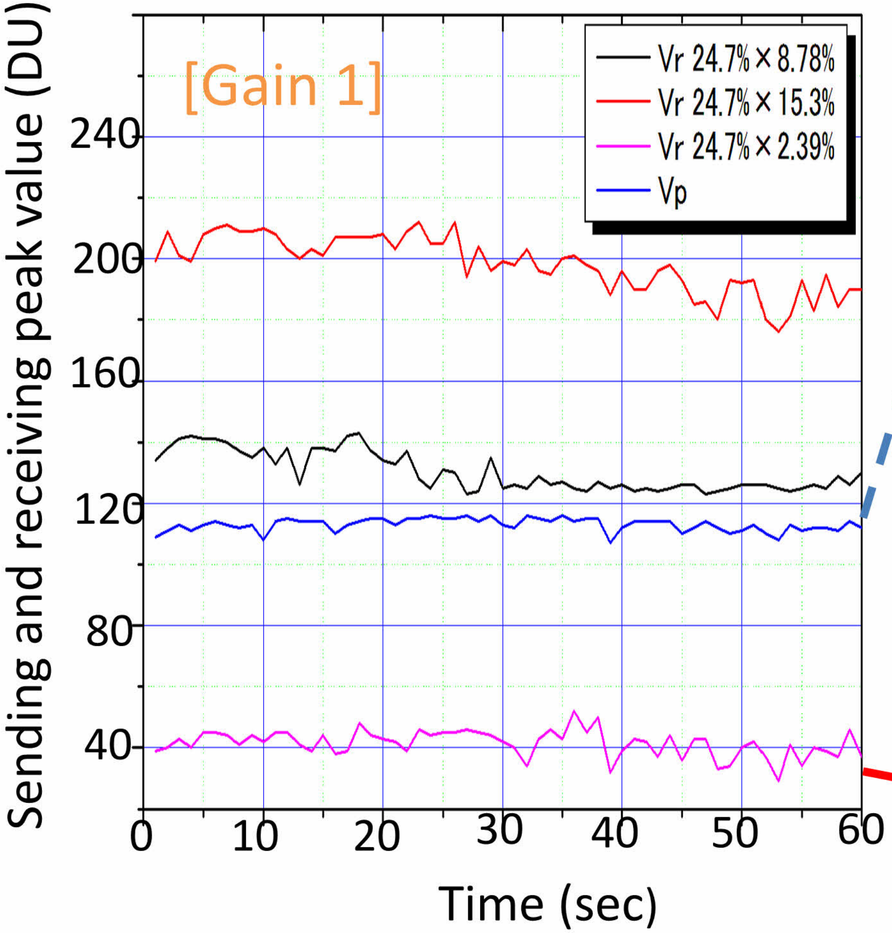
Evaluation of RR with Gain2,4,8 using the estimated laser input energy of the pulse LD



Experimental setup of LIDAR laser reflection

Measured Value of Intensity of the Receiving Laser

Measured intensities of the sending and receiving laser in the experiment.



We estimate the energy of sending laser E_J from the intensity V_P using the evaluated SR described above.

V_p

Estimation of the receiving energy

$$P_J = (E_J * F * \rho)/(\pi R^2)$$

F :Transmissivity of filter

ρ:Reflectance of the reflective board=0.1

R:Distance between the board and the LIDAR

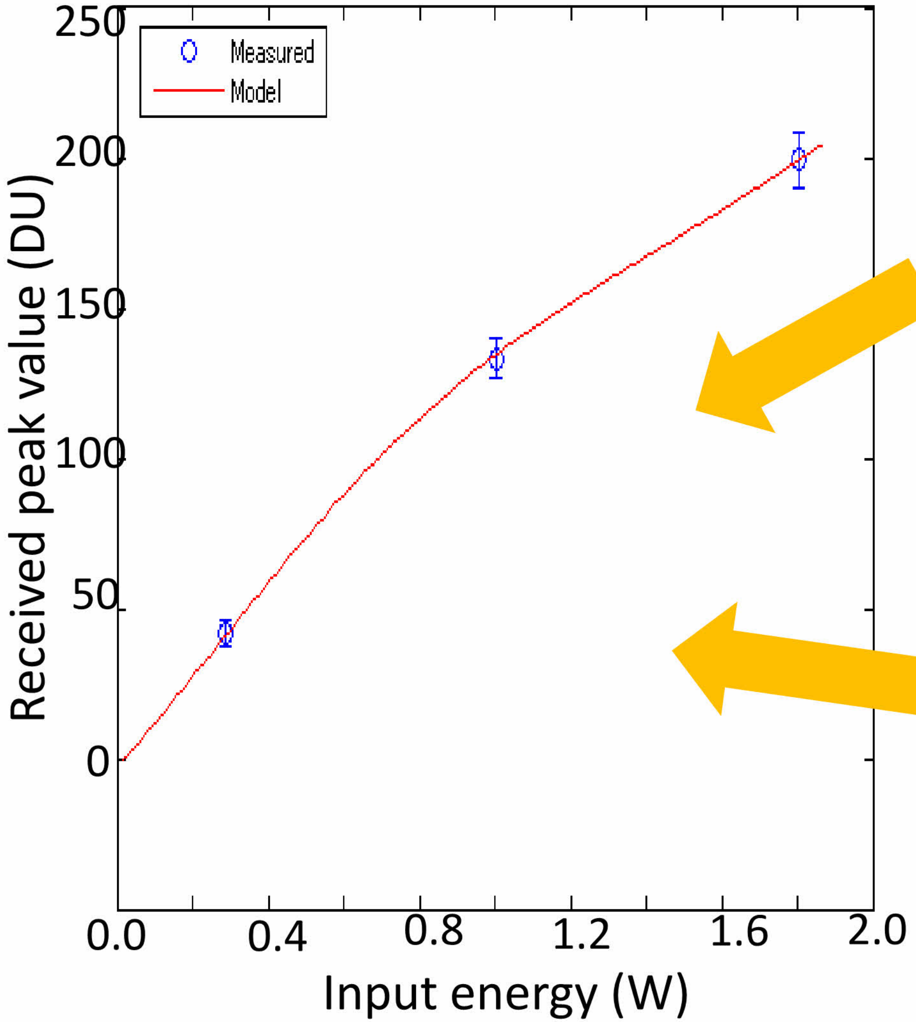
Intensity of the receiving laser V_r

Derivation of relation (RR) of energy and intensity of the receiving laser

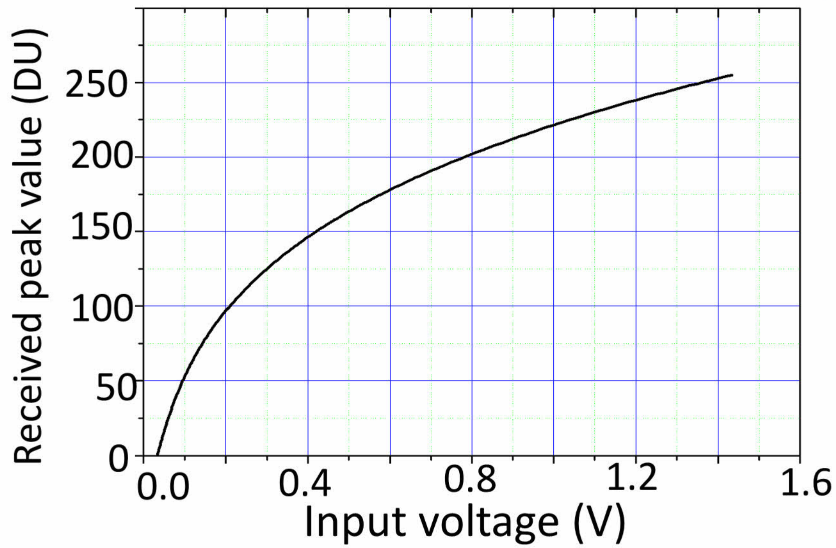
We measured three types of intensities changing the filter attached to the transmitter

Response of the LIDAR receiver (1)

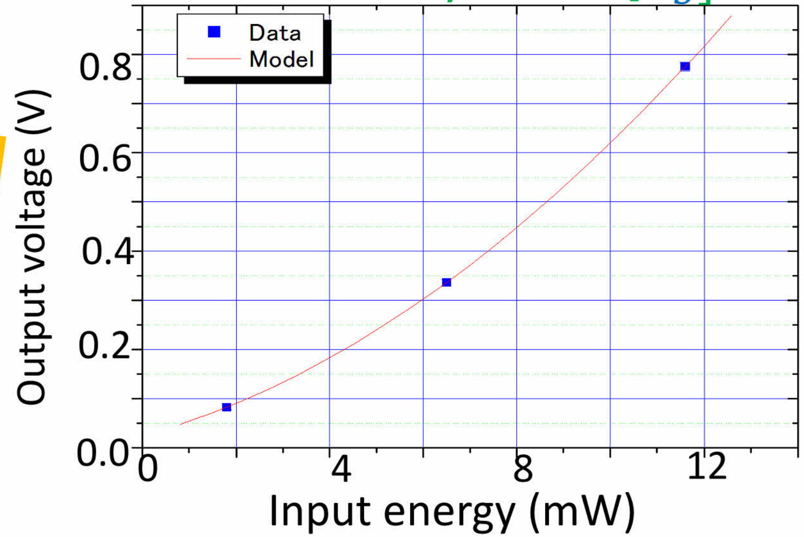
Response of the receiver with Gain1



Response of the receiver circuit[RT]



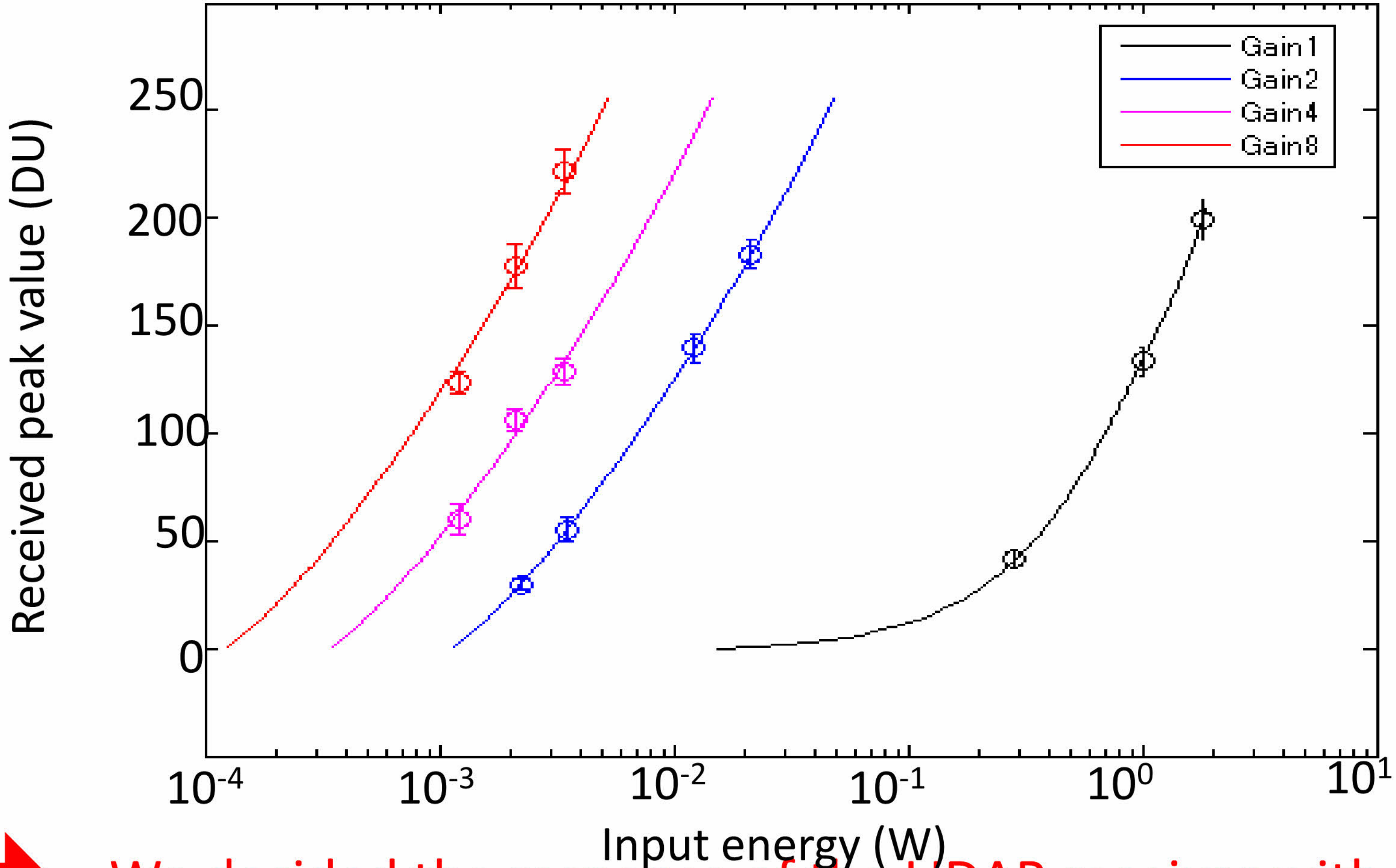
Sencitivity of APD[A_S]



We evaluated the response of the receiver from the measured data using the response of the receiver circuit and characteristic of the APD.

Response of the LIDAR receiver (2)

We evaluated responses of the receiver with Gain 2,4,8[RR] from the experiments based on the response of the Gain 1 .



We decided the response of the LIDAR receiver with error of about 11%.

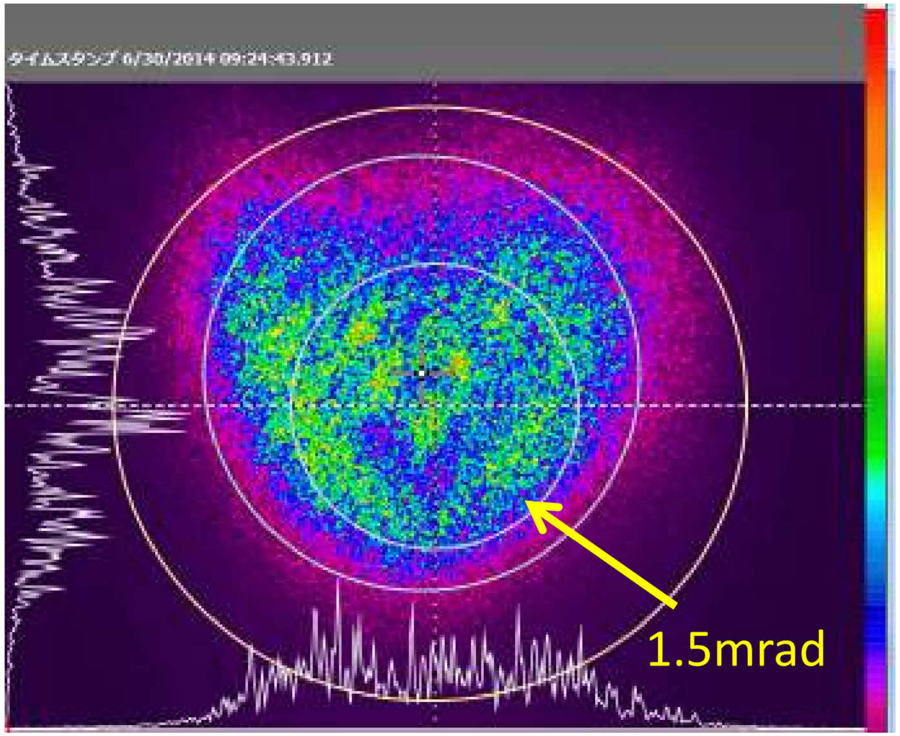
(On the other hand, we require more investigations of the response due to uncertainty of the Gain1)

Utilization Ratio of the Laser Energy

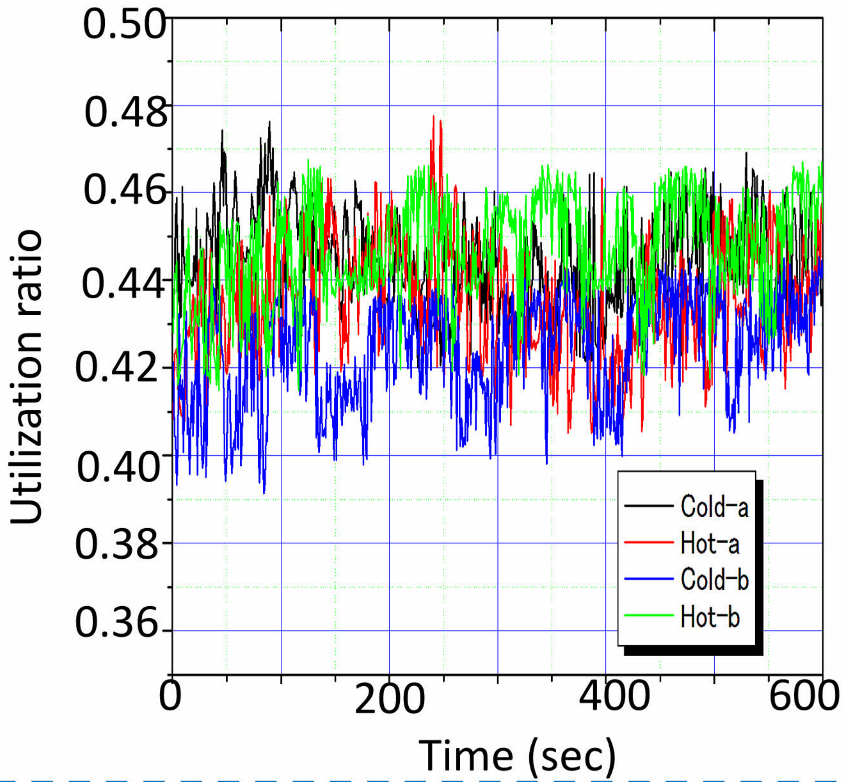
ε: Ratio of the sending laser energy input in the view of the receiver

We measured utilization ratio of the sending laser energy in the thermal and vacuum test.

Energy profile of the sending laser pulse of the LIDAR-FM



Variation of the utilization ratio

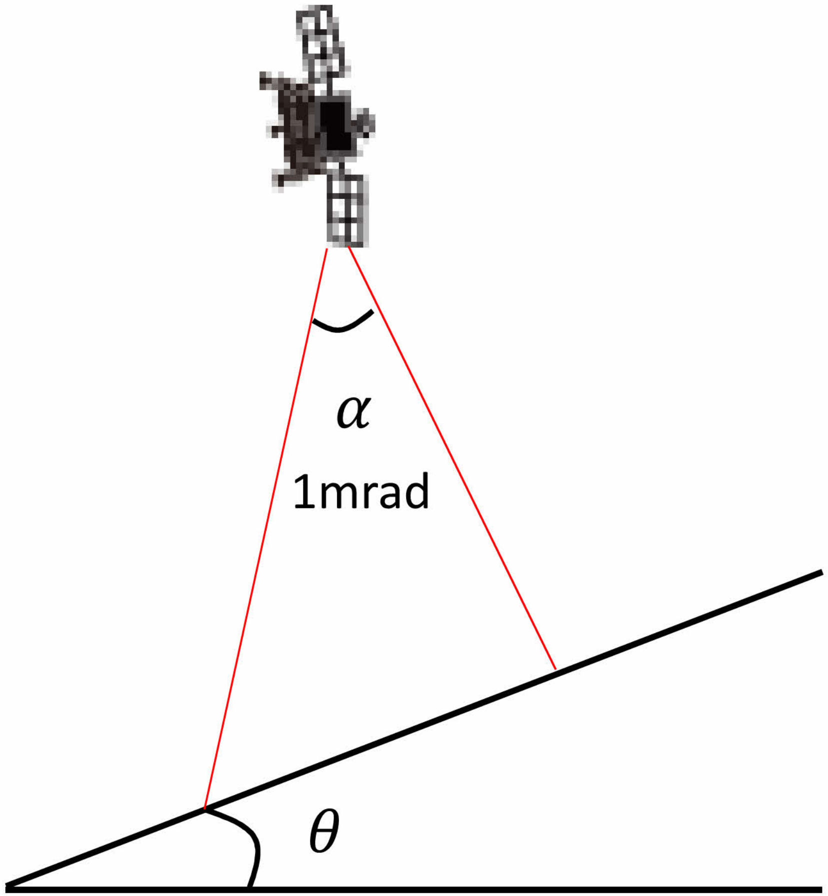


(Average and variance of the measured utilization ration among expected temperature condition)

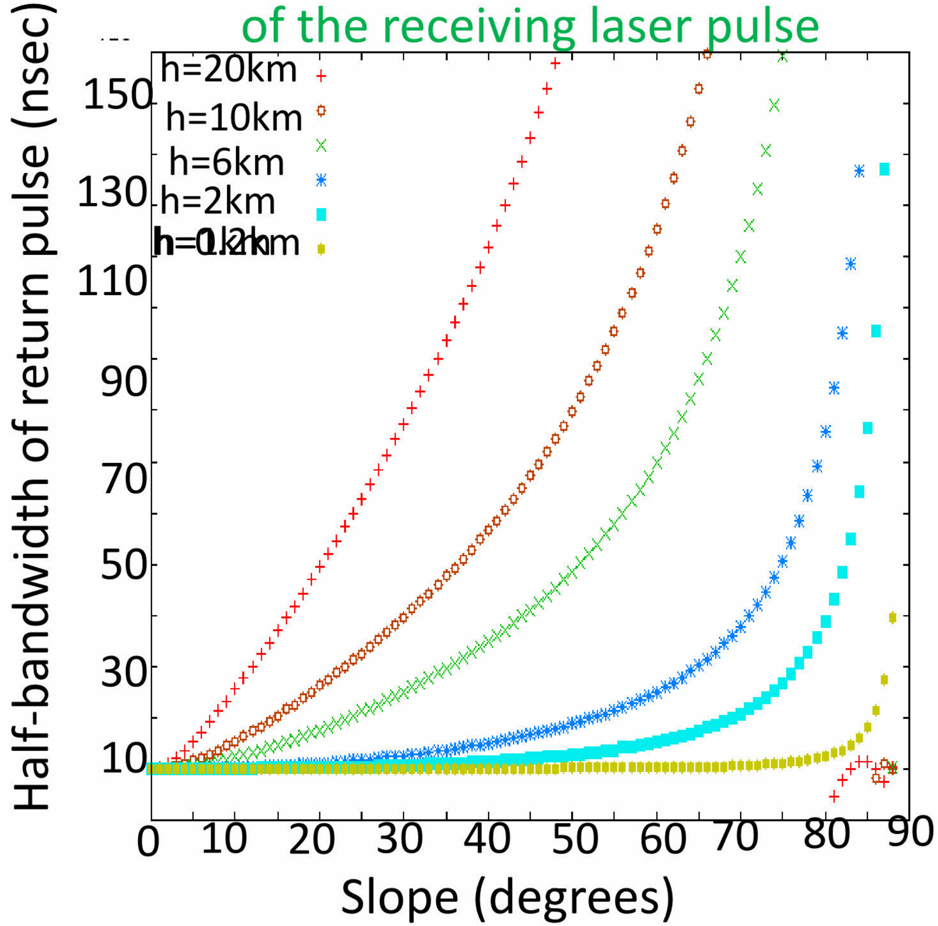
$$\varepsilon = 0.43517 \pm 0.014826$$

Effect of Asteroid Surface Slope

The shape of the receiving laser pulse changes due to change of arrival time of the laser in the footprint by slope of the asteroid surface.
（The degree of shape change depend on degree of the slope and the altitude of the spacecraft ）



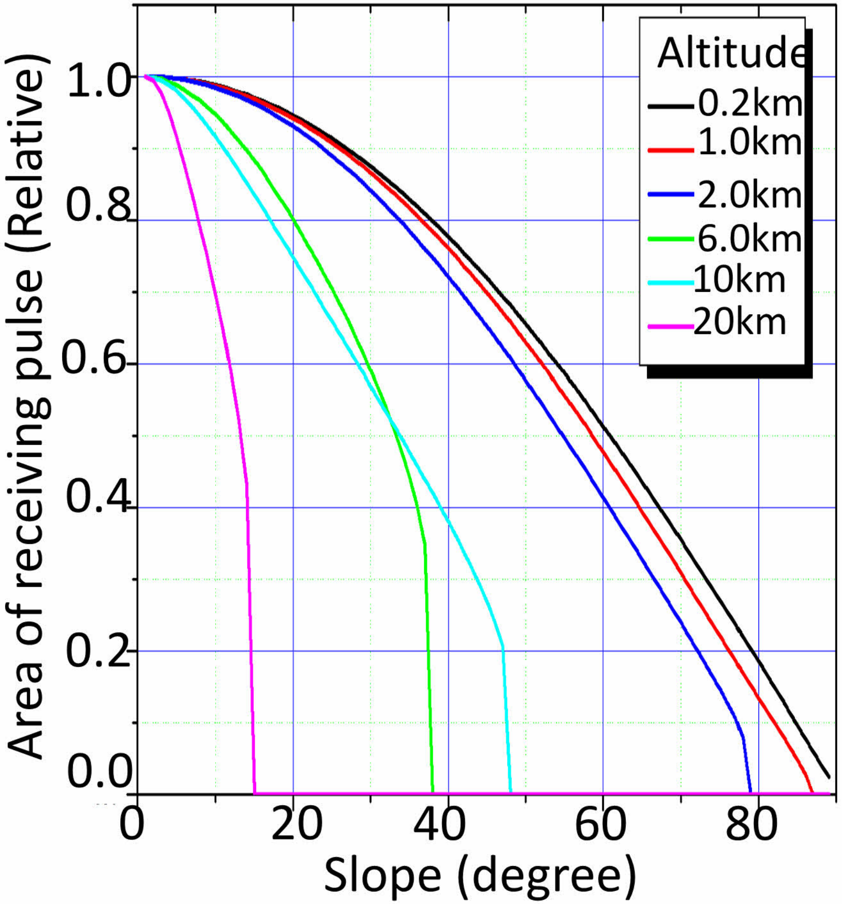
Change of the half bandwidth of the receiving laser pulse



Variation of the Intensity of Receiving Laser with the Slopes

The intensity of receiving laser (V_r) varies following responses of the integration and peak-hold circuits due to change of shape (area) of the receiving laser pulse effected by the asteroid surface slope.

Change of area of the receiving laser pulse
(The threshold is set at 30mV)



The variation of the V_r is larger at higher altitude.

Error of correction for V_r
(maximum resolution of the slope is assumed to be 1 degree)

○Home position(20km)

5deg slope: 3.69%

Maximum error slope: 17.3%

○Middle low altitude（6km)

5deg slope: 4.41%

Maximum error slope: 13.6%

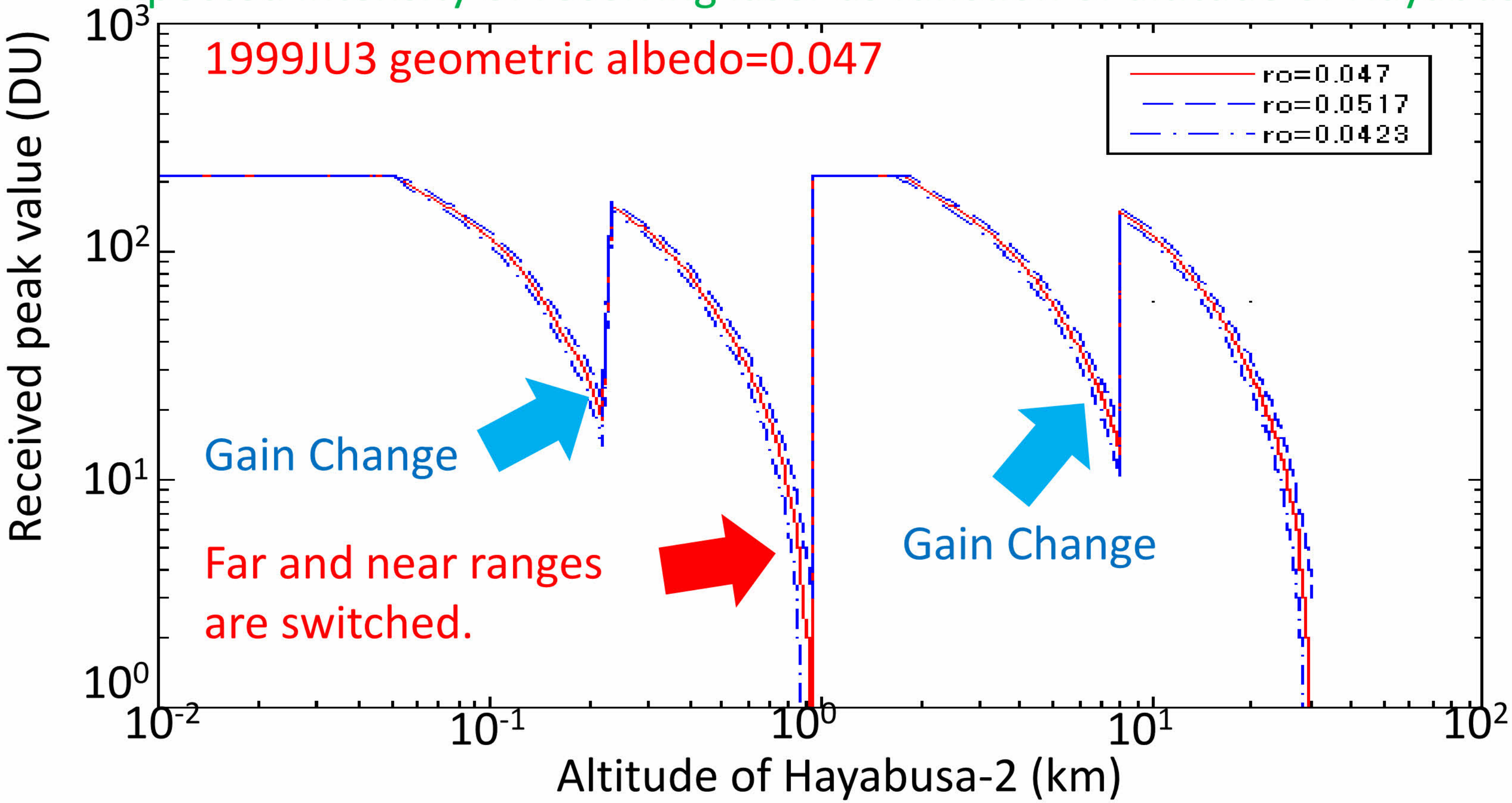
Expected Intensity of the Receiving Laser on Actual Operation

We estimated value of V_r expected during the operation of Hayabusa-2 using measured characteristics of the LIDAR

$$V_r = \frac{E_J * \varepsilon * \rho * RR}{\pi R^2}$$

The effects of surface slope and roughness are assumed to be perfectly corrected.

Expected intensity of receiving laser as function of altitude of Hayabusa-2



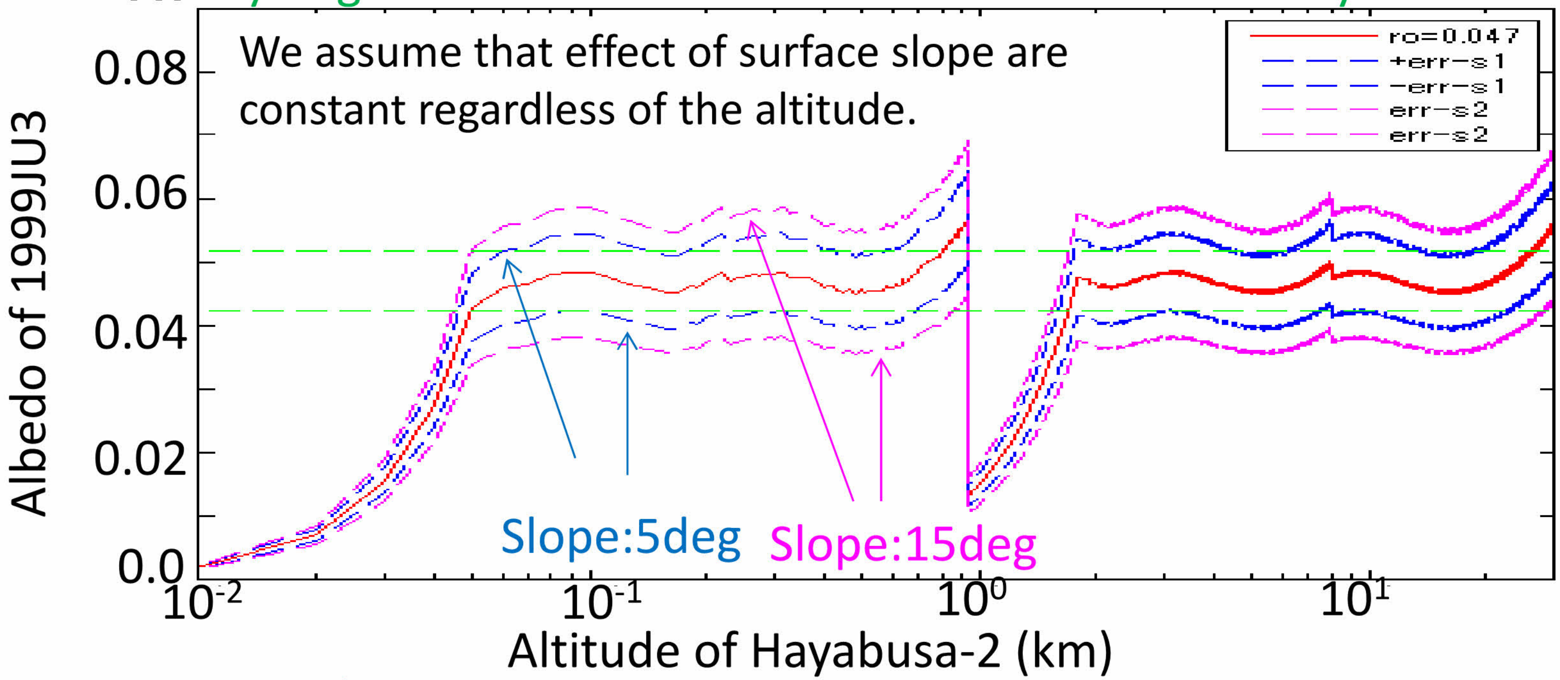
Accuracy of Geometric Albedo derived from the LIDAR

We evaluated accuracy of geometric albedo derived from the LIDAR data based on measured errors of the LIDAR characteristics and error of correction for V_r affected by the surface slope.

$$\delta\rho = \rho\sqrt{\left(\frac{\delta SR}{SR}\right)^2 + \left(\frac{\delta RR}{RR}\right)^2 + \left(\frac{\delta\varepsilon}{\varepsilon}\right)^2 + \left(\frac{\delta S(\theta)}{S(\theta)}\right)^2}$$

The effect of roughness is assumed to be perfectly corrected.

Accuracy of geometric albedo as function of altitude of Hayabusa-2

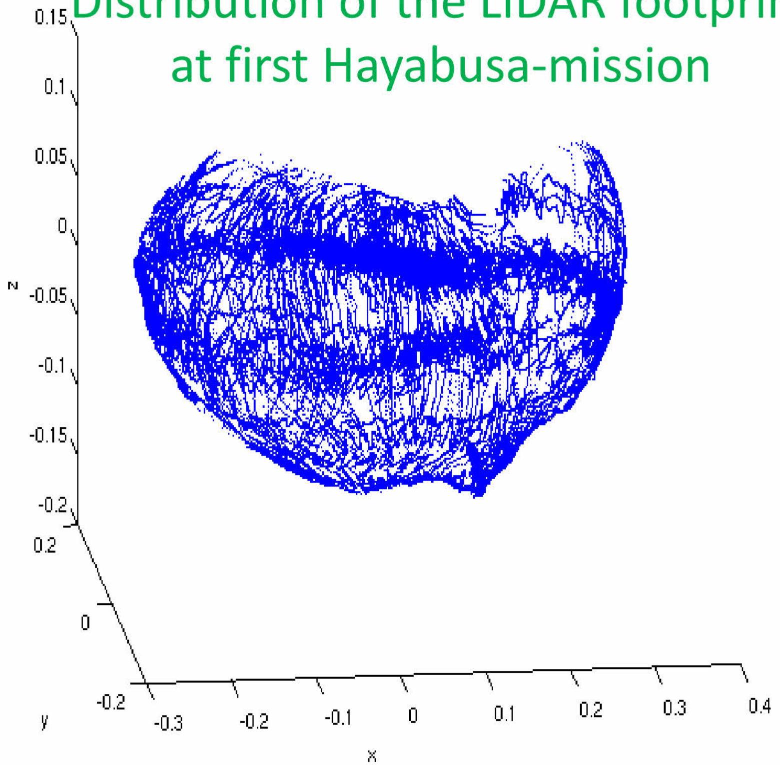


The accuracy of geometric albedo observation are 12-22% depending on the surface slope（In the case of Home position）

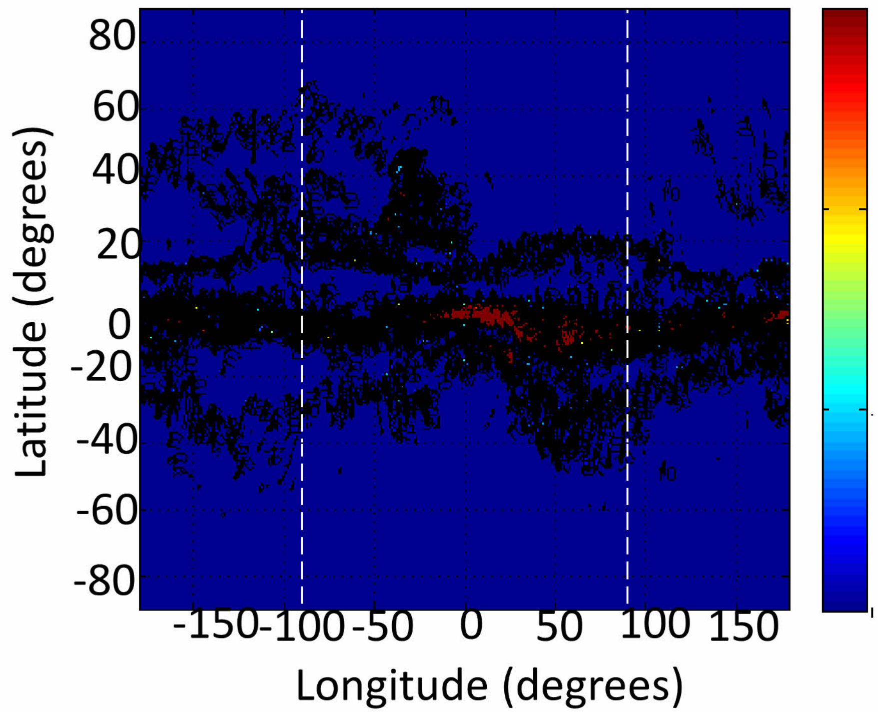
Improvement of Accuracy of the Geometric Albedo (1)

We consider reduction of error of geometric albedo by the data stacking on area where the footprints overlap

Distribution of the LIDAR footprint at first Hayabusa-mission



Overlap of footprint of LIDAR on Itokawa



Average of overlap around equator of Itokawa (latitude ±20degree)

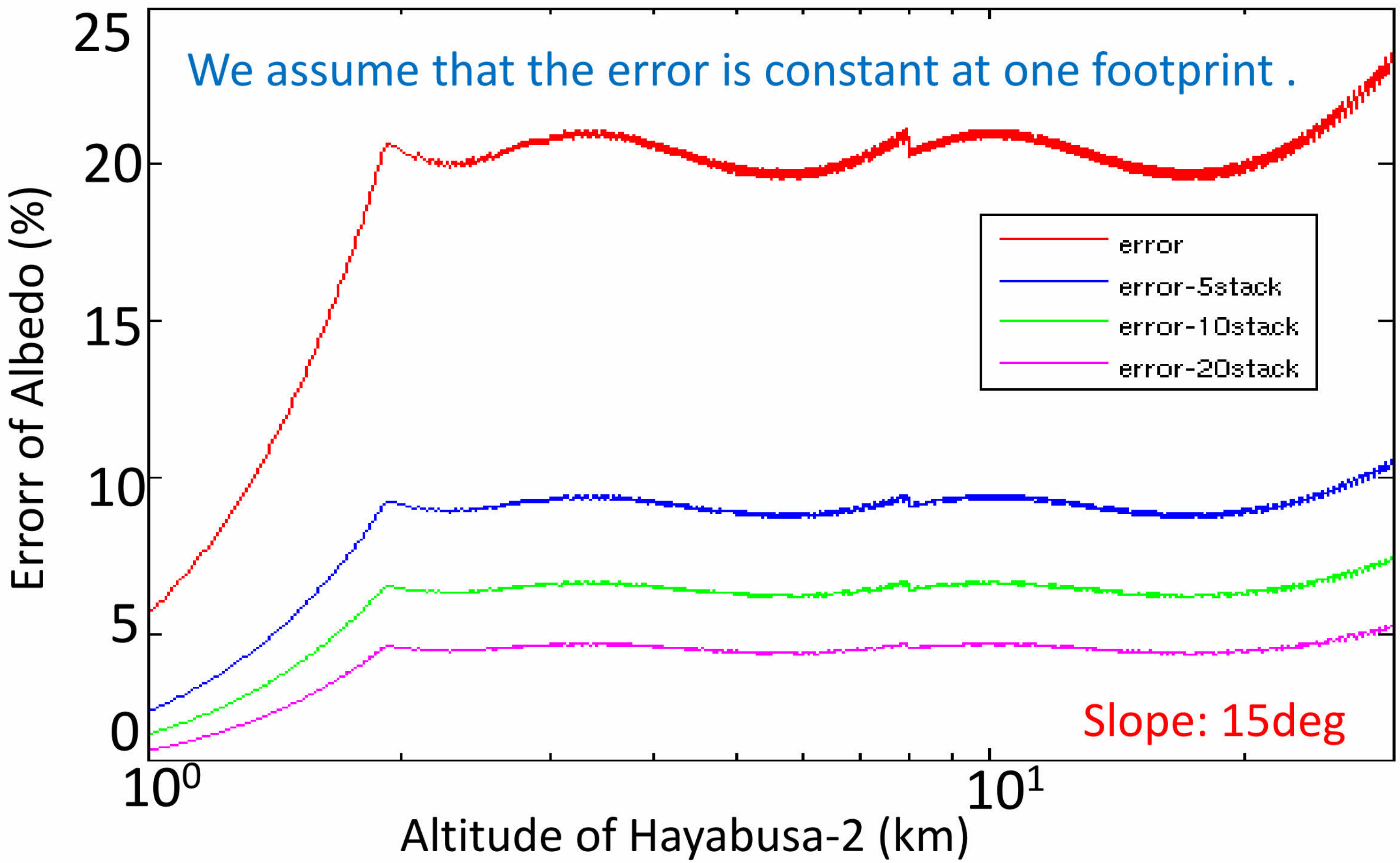
22.259±56.35 (1deg×1deg)

We can expect reduction of errors of geometric albedo depending on operation style of the Hayabusa-2.

Improvement of Accuracy of the Geometric Albedo (2)

We simulated how much the error of the geometric albedo can reduce by the data stacking,

Change of error of the geometric albedo with number of data stacking



We may be able to decide geometric albedo with error lower than 10% by data stacking over fifth even if the surface slope is large at the area.

Summary and Future Works

We investigated characteristics of the LIDAR required to estimate the geometric albedo (responses of the receiver and transmitter, the utilization ratio of the laser energy) and evaluated effect of the surface slope to the intensity of receiving laser.

[Current evaluated result about accuracy of geometric albedo]

Home-position(20km) : 5deg slope: 12.5%, 15deg slope: 22%
Middle low position(6km): 5deg slope: 13%, 35deg slope: 18%

We can reduce error of the albedo by data stacking on footprint overlap areas.

[Future works]

- More validation of response of the LIDAR receiver
- Evaluation of temperature characteristic of the LIDAR receiver
- More studies about effects of asteroid surface slope and roughness to the observed data by the LIDAR.