13-Po06: Noda et al.

# Alignment measurement with optical transponder system of Hayabusa-2 LIDAR

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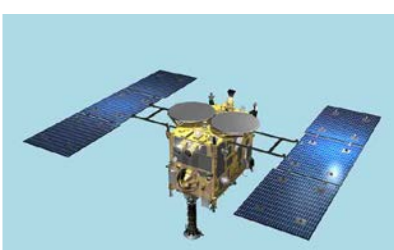
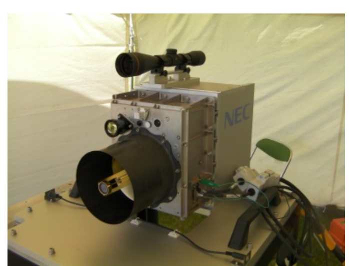


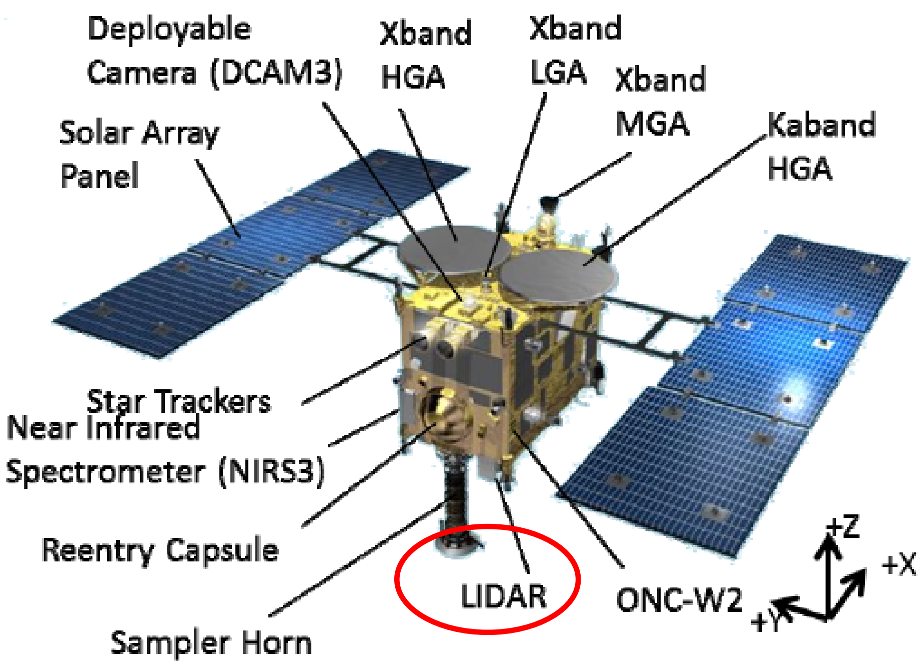


# Introduction

- Japanese Hayabusa-2 is a mission to C-type asteroid 1999 JU 3, and will be launched in 2014 winter
- LIDAR (Laser altimeter) is aboard Hayabusa-2 for navigation and geodetic science.
- LIDAR is equipped with "optical transponder" function for optical link experiment
- Optical link experiment between ground SLR station and Hayabusa-2 LIDAR is scheduled when satellite flies near Earth during Earth Swing-by in 2015 winter.
- The experiment will give the first opportunity to check the performance of LIDAR (link budget, alignment, ...)

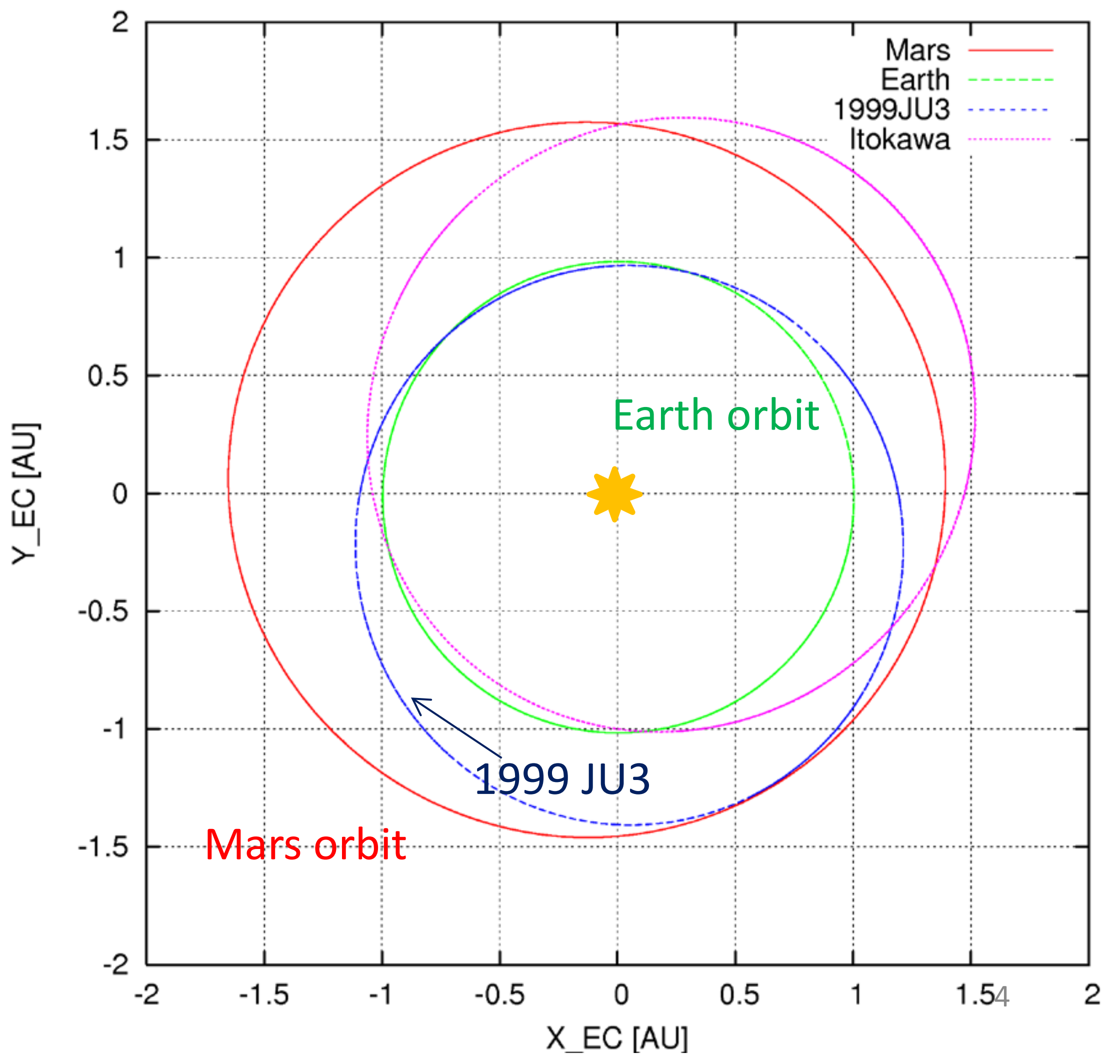
# Hayabusa-2 mission to asteroid

| Year/month | events |
|---|---|
| 2014/winter | launch |
| 2015/12 | Earth gravity assist |
| 2018/6 | Arrival at 1999 JU3 |
| | remote sensing, sampling |
| 2019/End | Departure from 1999 JU3 |
| 2020/12 | re-entry to Earth |
| | Research based on sample data |



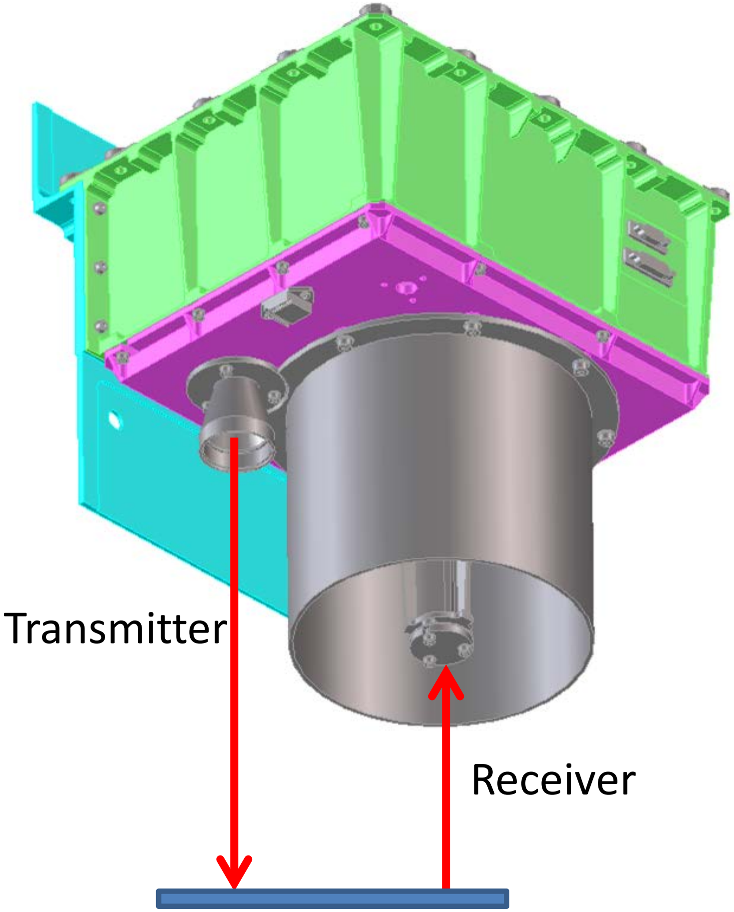
# Target asteroid 1999 $JU_3$

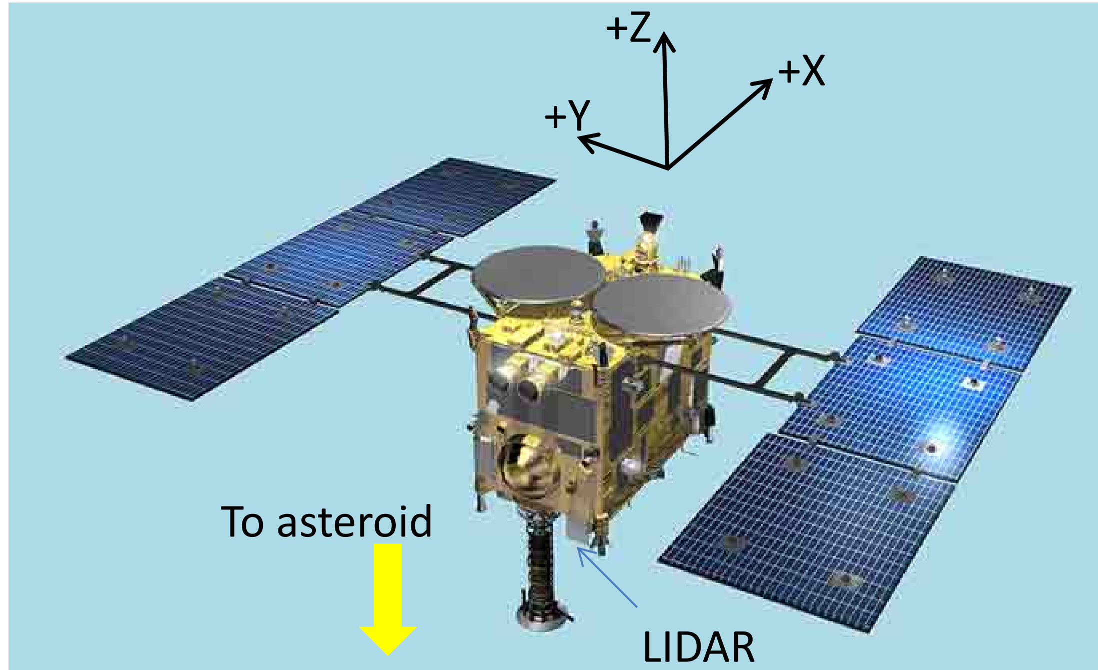
| | |
|---|---|
| Name | 1999 JU3 |
| Diameter | 0.9 km |
| Albedo | 0.05-0.07 |
| Spectral type | C |
| Rotation period | 7.63 hours |



# Hayabusa2 LIDAR

CAD drawing of LIDAR




Specification of LIDAR

| | |
|---|---|
| wavelength | 1064 nm |
| Laser power | 10 mJ |
| Repetition rate | 1 Hz |
| Pulse width | <10 nsec |
| Transmitter FOV | 1 mrad |
| Receiver FOV (far) | 1.5 mrad |
| Range resolution | 0.5 m |

# Science targets by LIDAR

- Shape modeling and gravity measurement gives average porosity of target asteroid, which is important to characterize the asteroid
- Albedo measurement at laser wavelength: with visible and Near-IR albedo data, it will constrain the surface material
- Detection of levitation dust : so far there is no observational evidences of circum-asteroid environment. If detected, it will be the first observation of dust around asteroids.

# Measurement requirement

(Namiki et al, submitted)

- Porosity is a key parameter to characterize asteroids
- Porosity can be estimated from volume and mass
- 10% uncertainty
  ←density 10%
  ←volume 5%, mass3%
  ←radius< 2 %( ~10m)

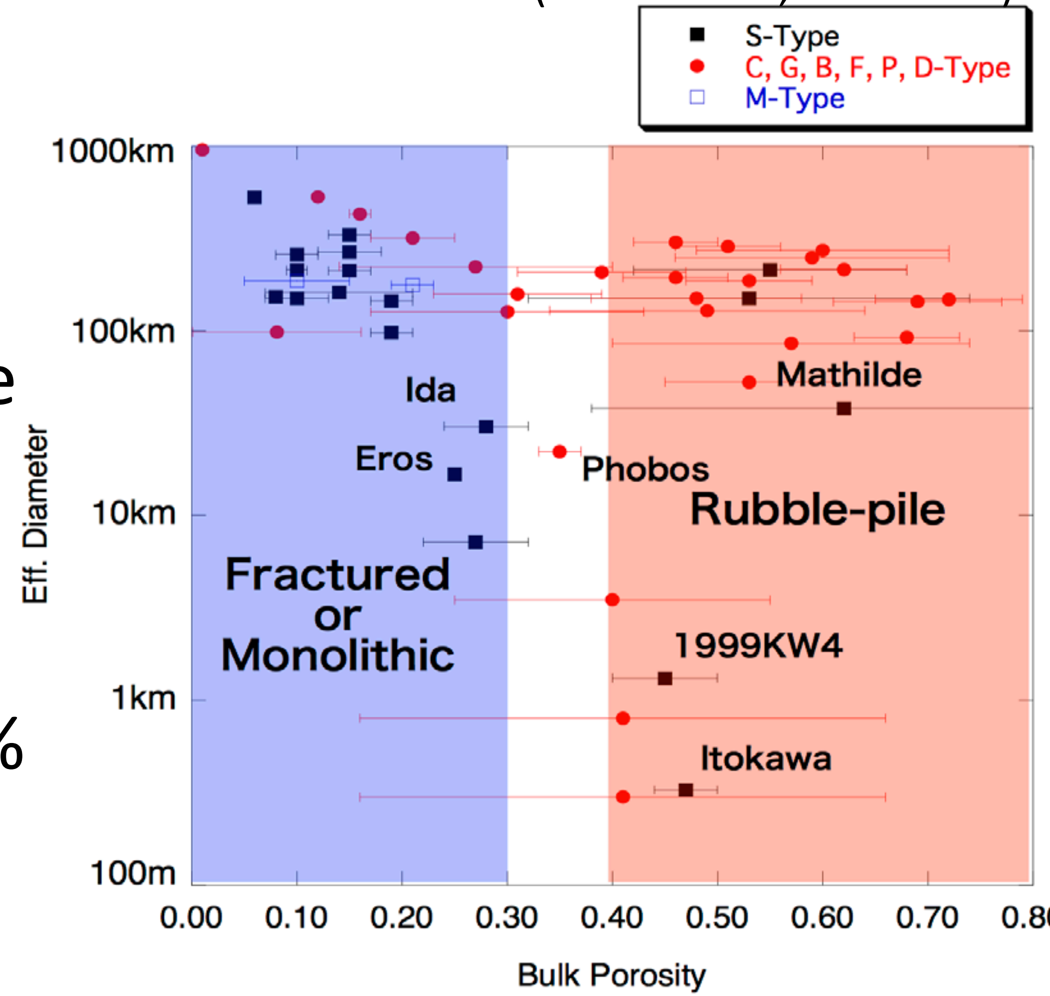
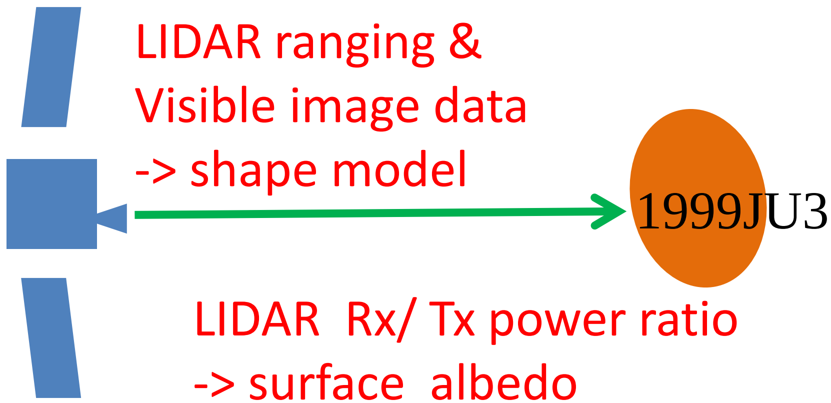
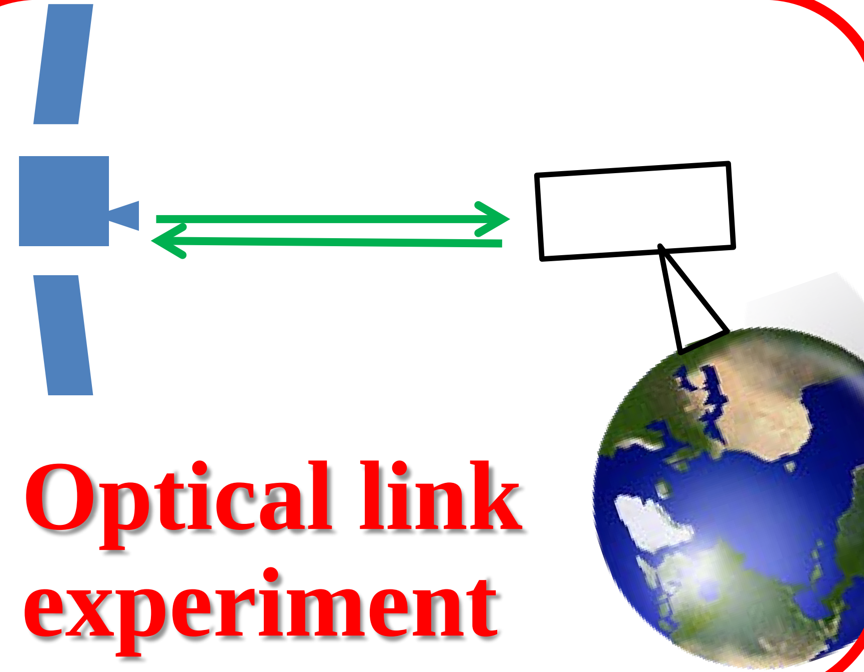



**Figure 2.** Relation of effective diameter and bulk porosity of asteroids. In addition to estimates by *Baer et al.* [2011], data taken from literatures are shown. Inferred internal structures such as fractured, monolithic and rubble-pile are based on classification by *Britt et al.* [2002]. Microscopic porosity is assumed to be 10 % that is a typical value of meteorites.

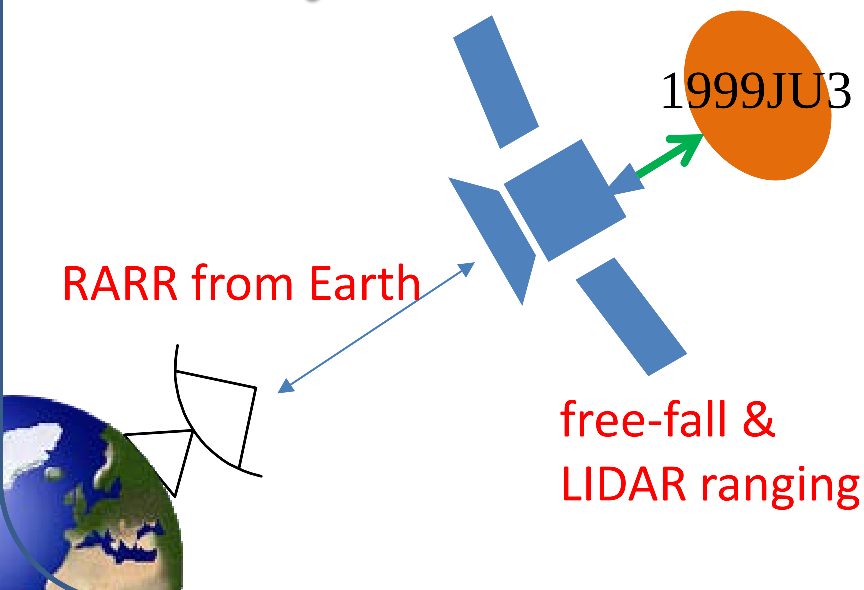
# Shape modeling & albedo



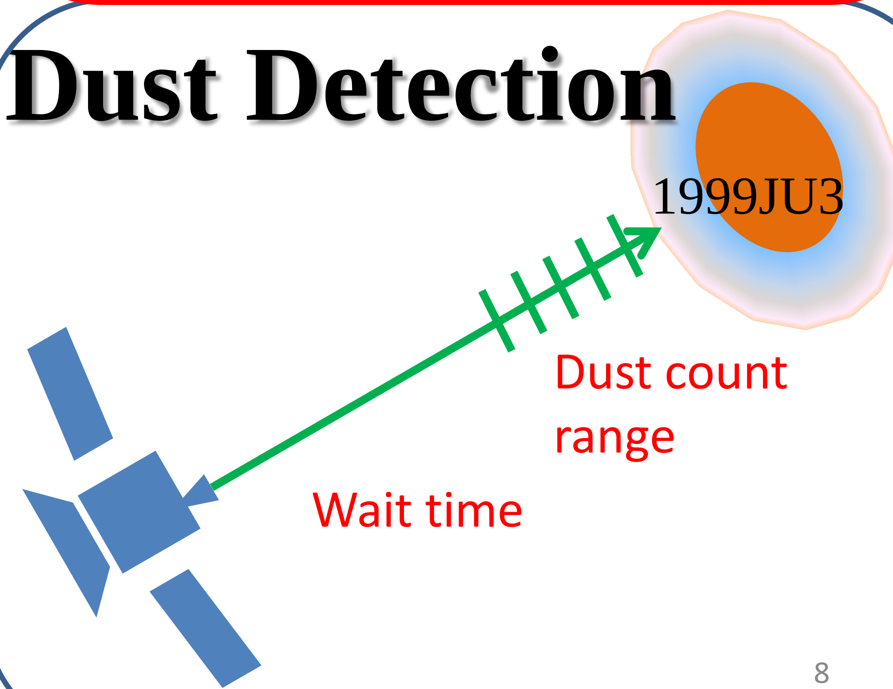

# Optical link experiment



# Gravity measurement

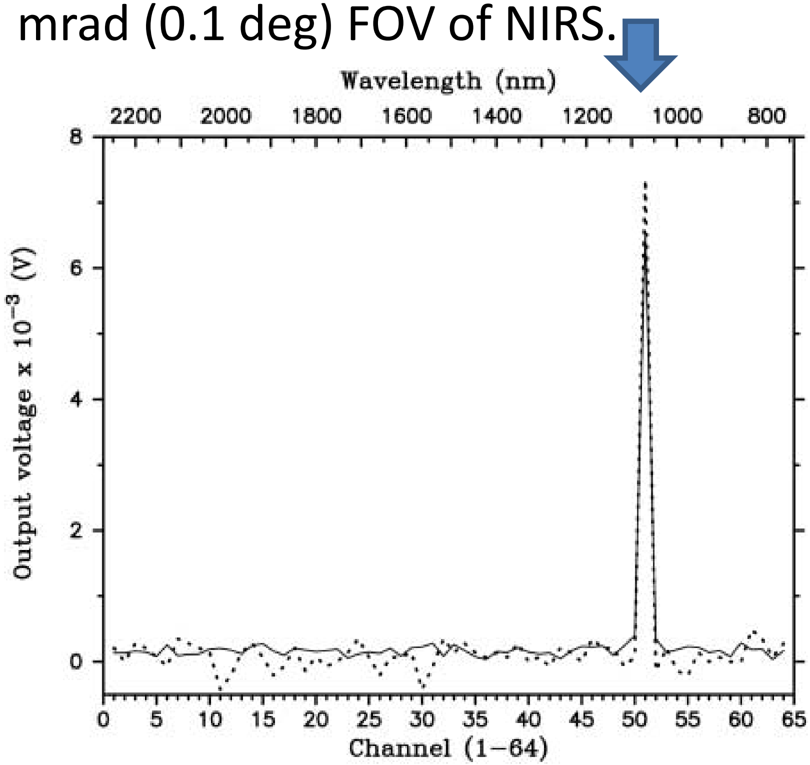



# Dust Detection



# Hayabusa vs Hayabusa-2 alignment measurement

- In Hayabusa, NIRS has 1 um band, where the LIDAR footprint could be detected so that the LIDAR boresight direction was determined within 1.7 mrad (0.1 deg) FOV of NIRS.




Abe et al. Science 2006 Fig. 1

- In Hayabusa-2, no sensitivity at 1 um range in NIRS3*.
- Optical link experiment gives opportunity to determine alignment w.r.t. spacecraft.
- As FOV of LIDAR transmitter is 1 mrad and spacecraft attitude error is 0.5 mrad, boresight direction will be determined within 1.5 mrad.
- 1.5mrad accuracy satisfies the requirement of the volume measurement of asteroid.

*NIRS3 = Near Infrared Spectrometer at 3 μm

# Telescope parameters

| parameter | NICT 1.5m | LIDAR |
|---|---|---|
| **Transmitter** | | |
| wavelength, nm | 1064 | 1064 |
| Laser pulse energy, mJ | 1200 | 10 |
| Repetition frequency, Hz | 10 | 1 |
| Pulse width, ns | 10 | <10 |
| Beam divergence, mrad | 0.01 | 1 |
| **Receiver** | | |
| Telescope diameter, m | 1.5 | 0.11 |
| Detector FOV, mrad | 0.1 | 1.5 |
| **Pointing** | | |
| Pointing accuracy, mrad | ~ 0.01 (~2 arcsec) | 0.5 (attitude stability) |
| **Scanning** | | |
| Scan rate, mrad/s | TBD ( arcsec step) | 0.5 TBD |
| Scan amplitude, mrad | TBD | 5 |

# Link equation

Uplink : NICT 1.5m -> LIDAR
Downlink: LIDAR -> NICT1.5m

Uplink case, the receiving power Ps [W] (uplink) is calculated as follows:

$$P_s = P_t \bullet \eta_t \bullet G_t \bullet \eta_r \bullet L_p \bullet L_s(r) \bullet G_r \bullet L_0$$

, which is converted to output voltage of detector (APD) with 500kV/W responsivity

Downlink case, single photon is detected with APD Geiger mode at ground station, therefore the number of photoelectorn Npe is a measure of detection, which is calculated by using laser energy Et as follows:

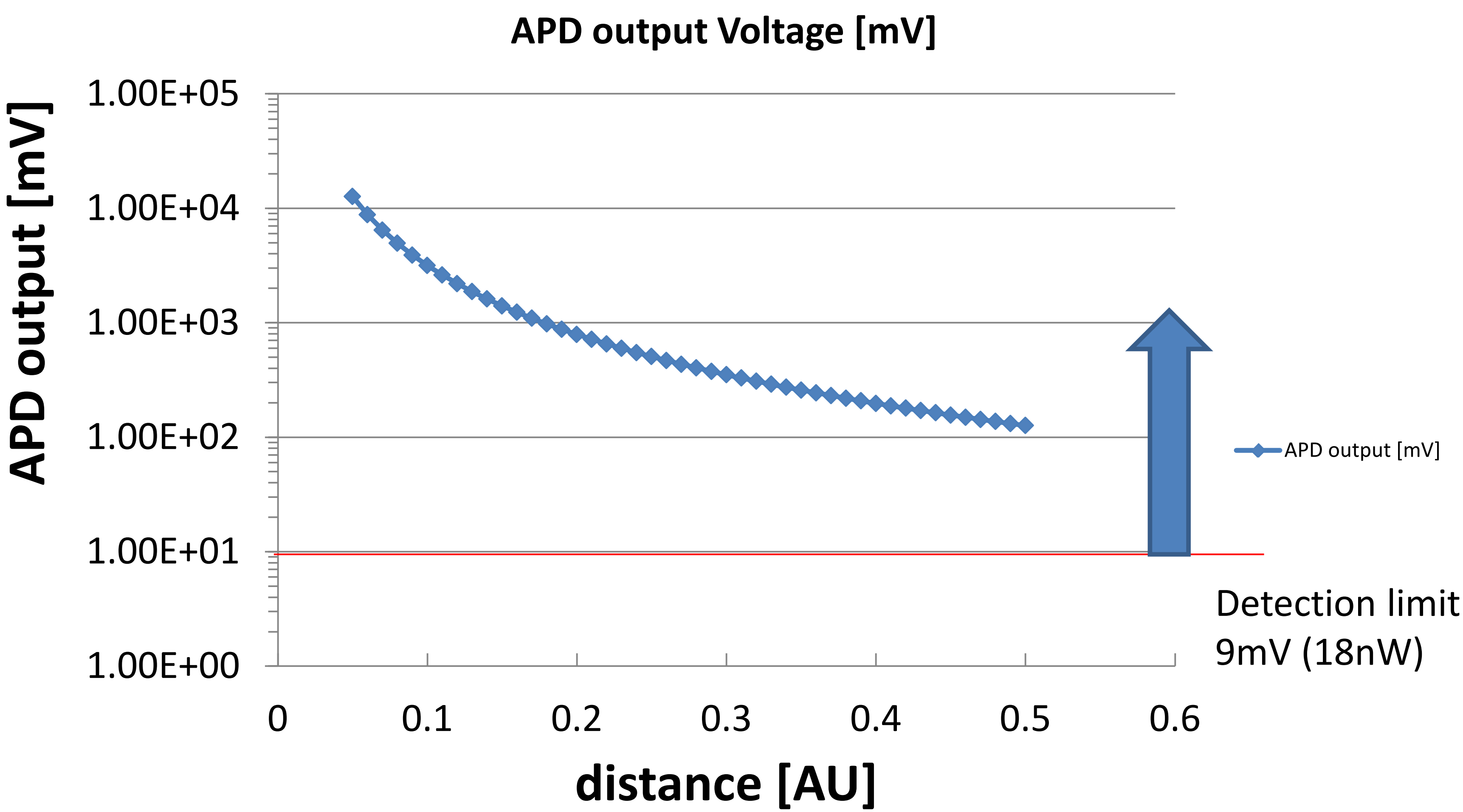
$$N_{pe} = \eta_q \bullet (E_t / h\nu) \bullet \eta_t \bullet G_t \bullet \eta_r \bullet L_p \bullet L_s(r) \bullet G_r \bullet L_0$$

# Link equation: parameters

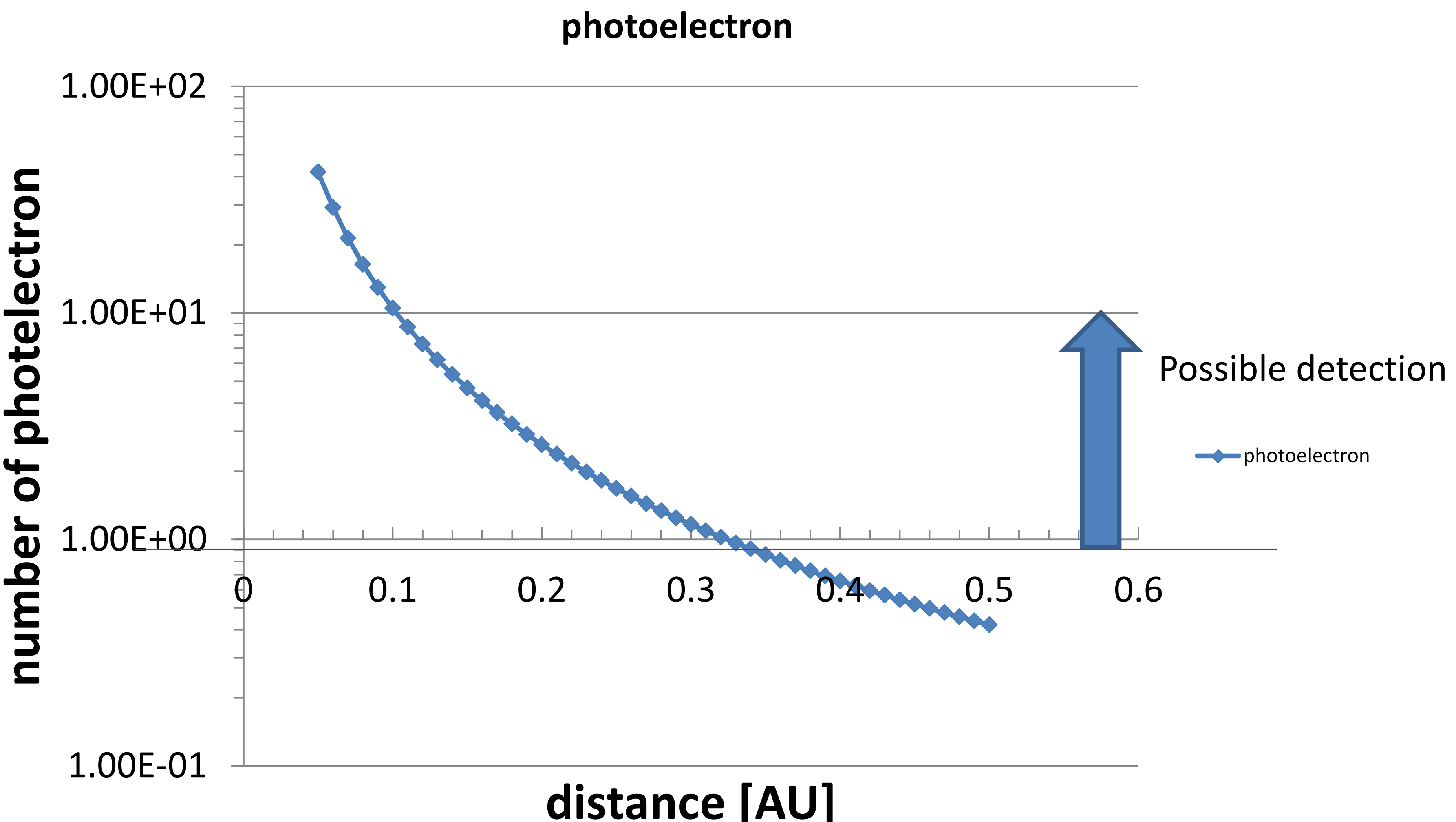
| Symbol | meaning | Value(uplink) | Value(downlink) |
|---|---|---|---|
| $P_t$ | Transmitter power | 120 MW (/pulse) | -- |
| $E_t$ | Transmitter energy | -- | 0.01 J |
| $\eta_q$ | Quantum efficiency | -- | 0.2 |
| $\eta_t$ | Transmitter efficiency | 0.8 | 0.8 |
| $G_t$ | Transmitter gain * | 1.6E11 | 1.6E7 |
| $\eta_r$ | Receiver efficiency | 0.5 | 0.5 |
| $L_p$ | Pointing loss | 0.487 | 0.487 |
| $L_s(r)$ | Space loss | 1.2E-34 @ 0.05 AU | |
| $G_r$ | Receiver gain | 1.05E11 | 1.96E13 |
| $L_0$ | Other losses | 0.5 | 0.5 |

* Calculated from beam divergence angle

# Link budget (uplink)

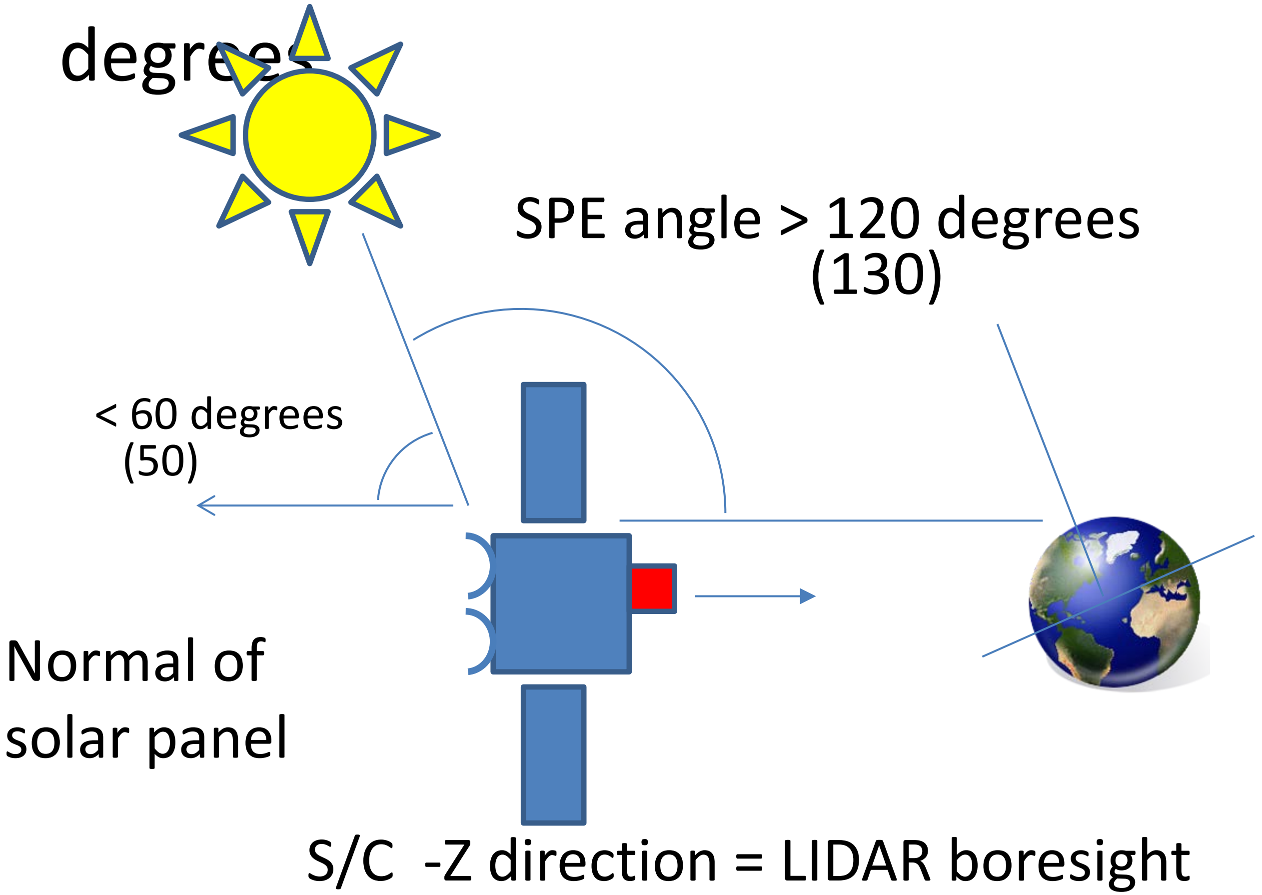


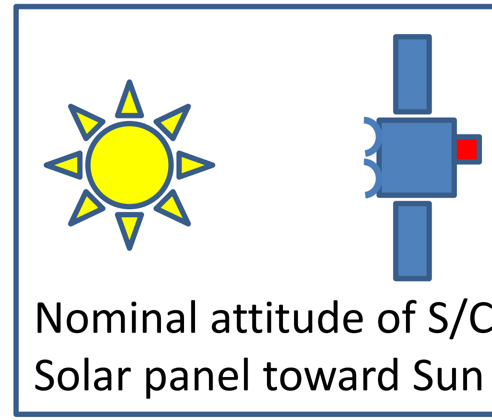
# Link budget (Downlink)



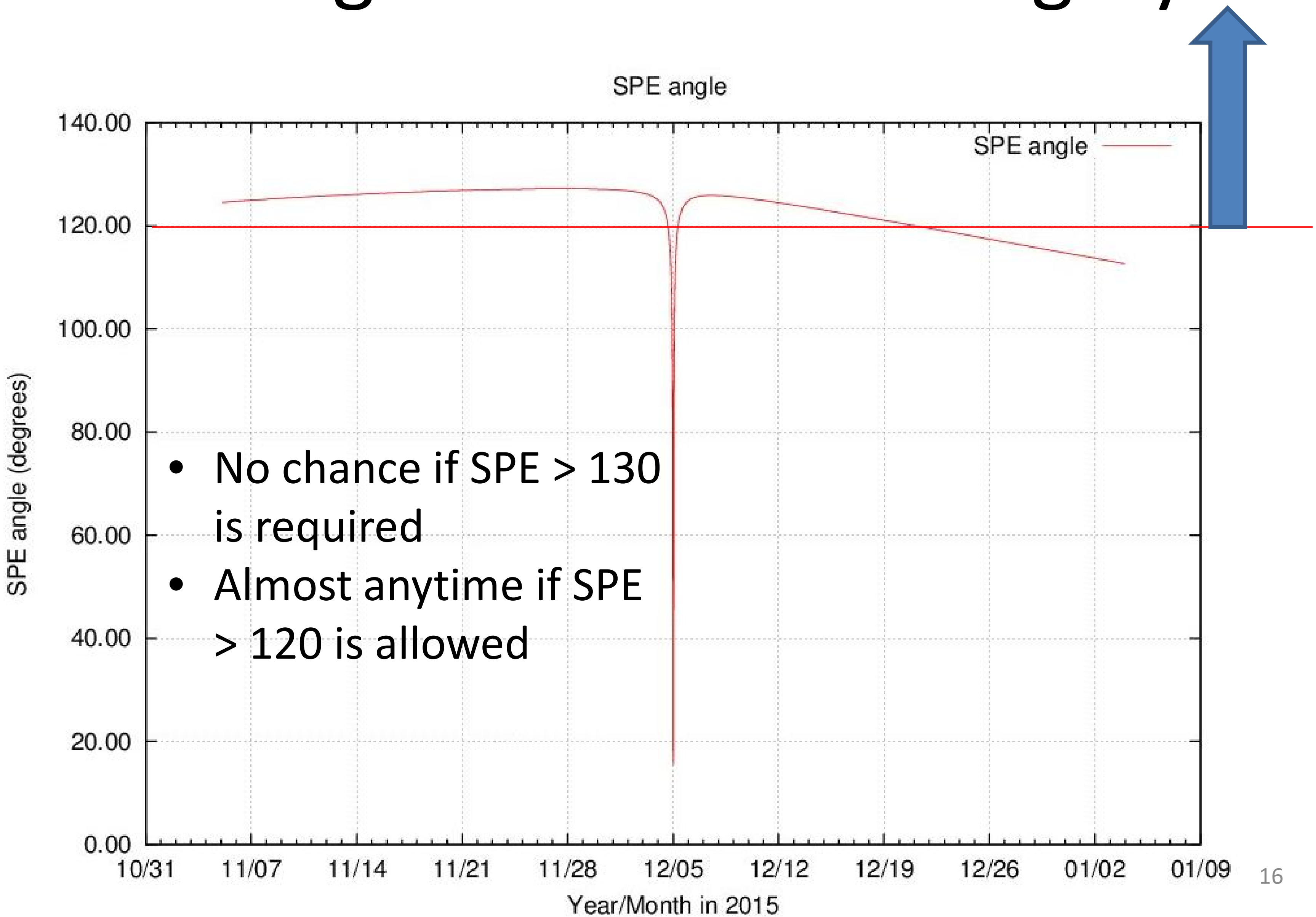
# Sun-Spacecraft-Earth angle limitation (SPE angle>120 or 130 degrees)

- The angle between Sun direction and normal of the solar panel must be within 60 (or 50) degrees



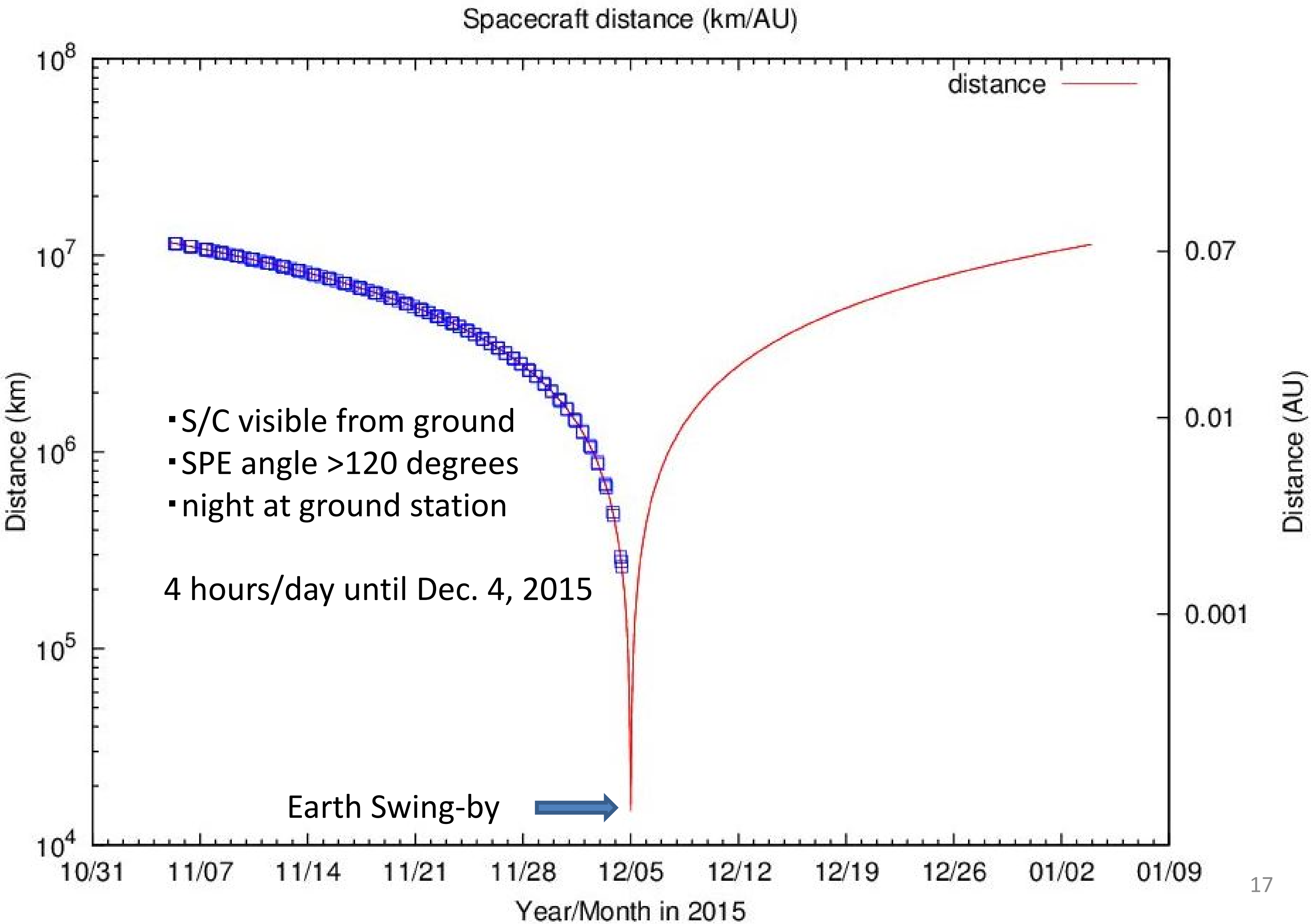



# SPE angle near Earth Swing-by

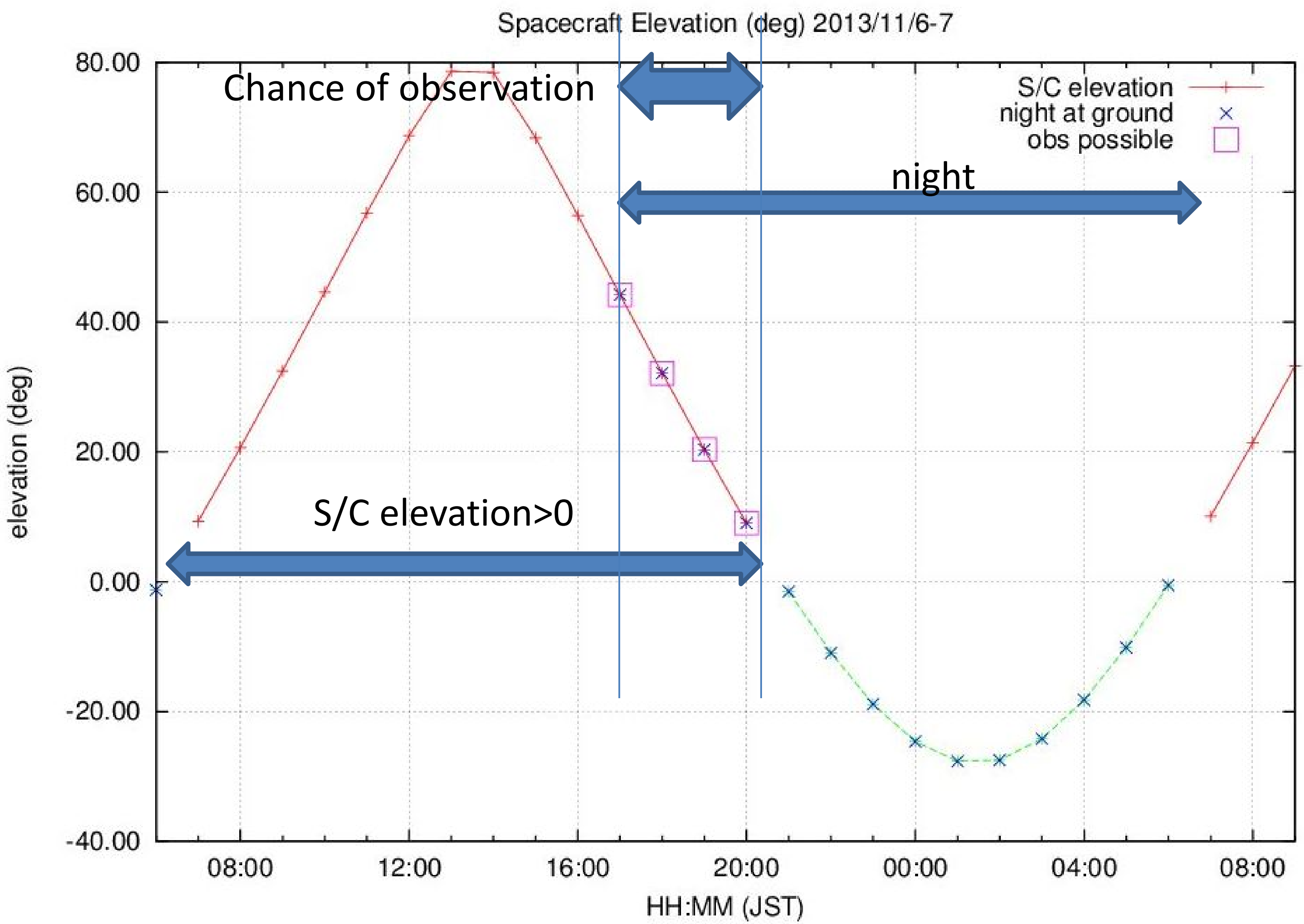


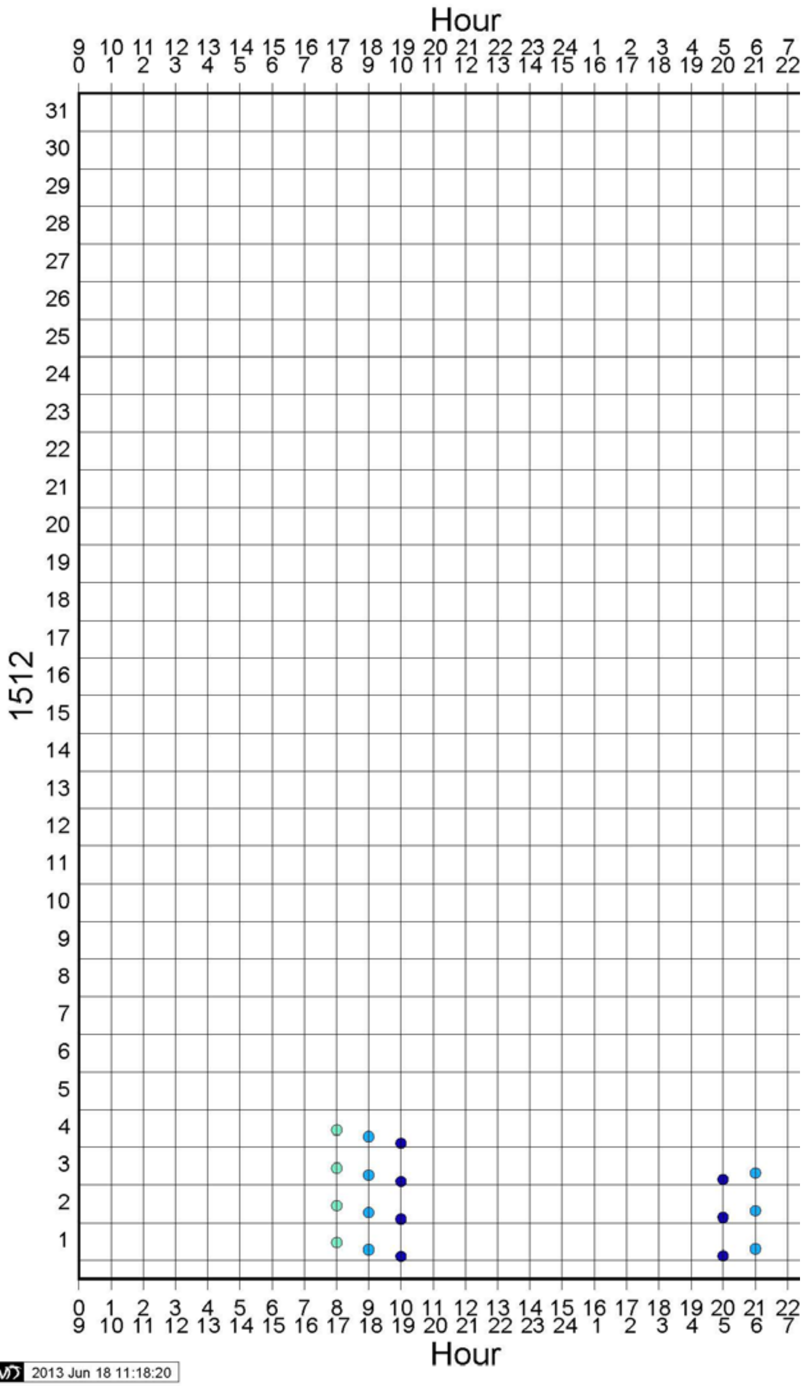

- No chance if SPE > 130 is required
- Almost anytime if SPE > 120 is allowed

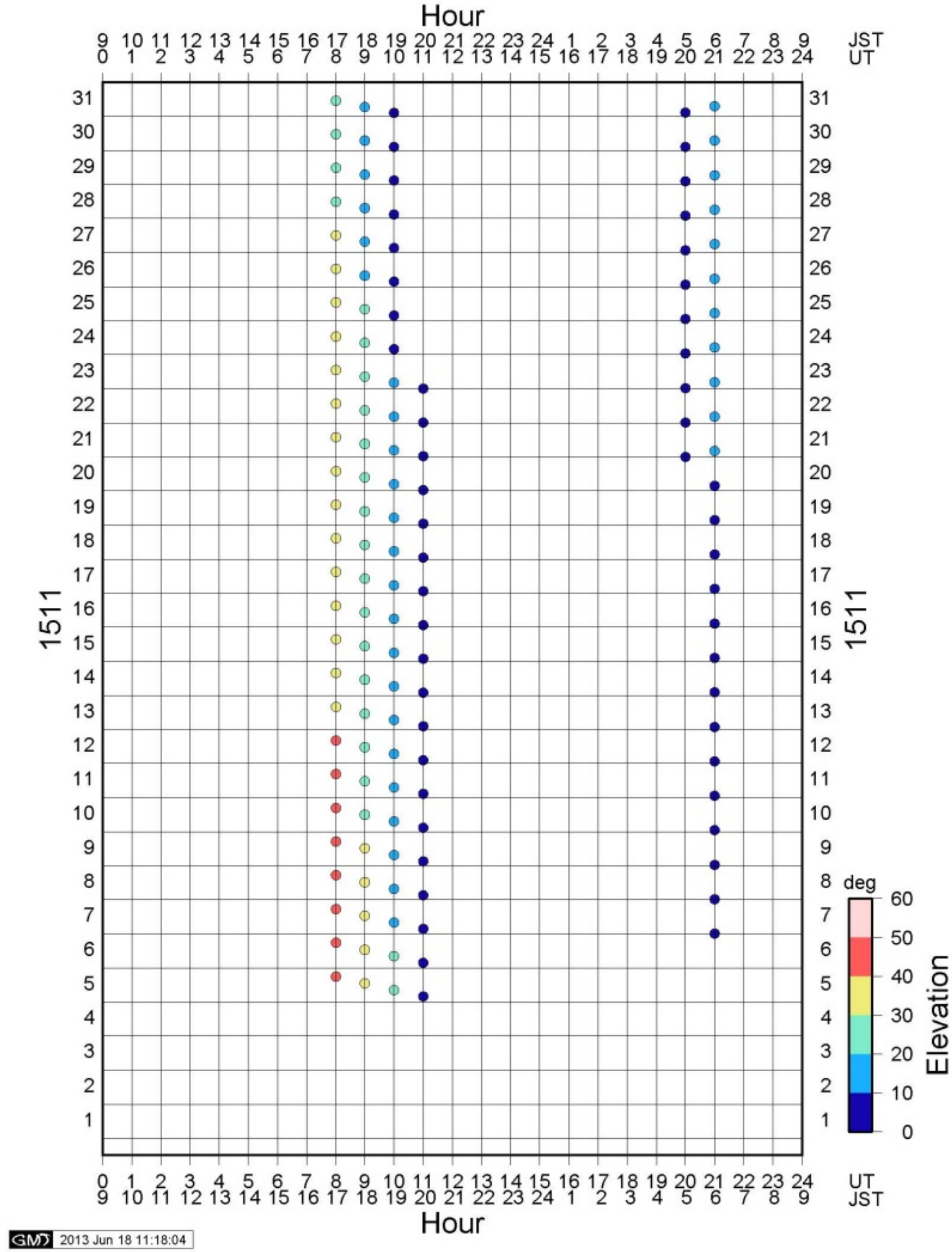
# Chances of experiment at Koganei



# An example: Nov. 6, 2015




Hour
1512
Hour
2013 Jun 18 11:18:20


Hour
JST
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Hour
2013 Jun 18 11:18:04

# Summary

- If opt-link is possible, it can constrain the LIDAR FOV alignment w.r.t. spacecraft within 1.5 mrad.
- Link budget
  - Uplink:  further than the downlink case is possible
  - Downlink: up to 0.3 AU might be possible
- Chance of observation
  - 4 hours/day is possible at least within a month prior to Earth swing-by