Status of X-ray Astronomy Satellite Hitomi (ASTRO-H)

April 15th, 2016

JAXA

Time in this material is expressed in JST

（Blank）

Contents of explanation today

- In the previous press briefings, JAXA has reported 3 events, “attitude anomaly”, “objects separation” and “communication anomaly”, occurred around the in-flight anomaly of ASTRO-H at 16:40(JST), March 26, 2016.
- Today, JAXA will report the presumptive mechanism of the series of flow from “normal status” to “attitude anomaly”, and “objects separation”.
- JAXA plans to investigate the mechanism of “communication anomaly”.
- JAXA is also investigating background factors that lead the incidents above.

1. Presumed Mechanism(Summary)

(From “Normal situation” to the “Attitude anomaly Event”, and “Objects separation”)

（1）On March 26th, attitude maneuver to orient toward an active galactic nucleus was completed as planned.

（2）After the maneuver, unexpected behavior of the attitude control system (ACS) caused incorrect determination of its attitude as rotating, although the satellite was not rotating actually. In the result, the Reaction Wheel (RW) to stop the rotation was activated and lead to the rotation of satellite.【Presumed Mechanism 1】

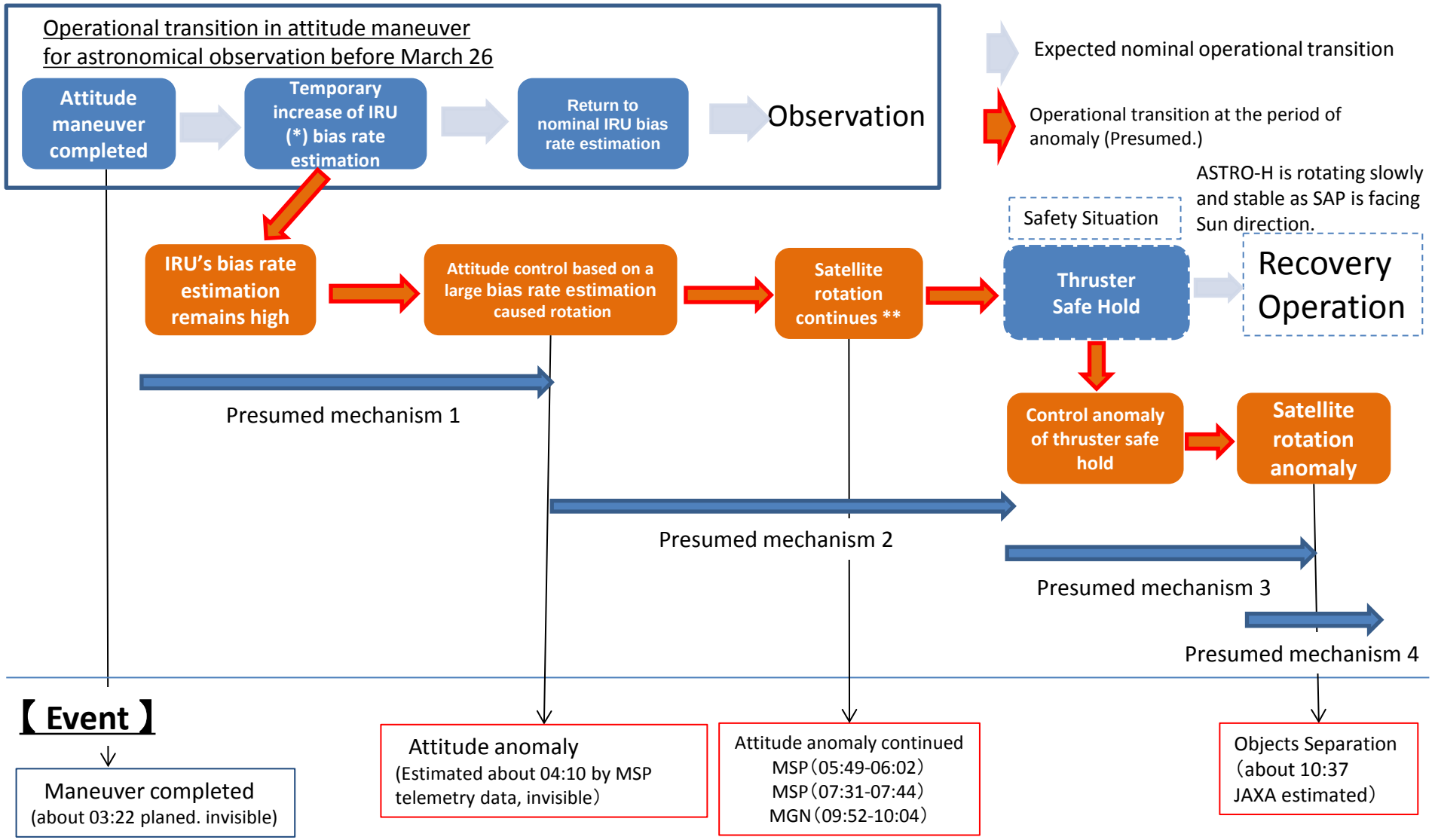
（3）In addition, unloading(*) of angular velocity by Magnetic Torquer operated by ACS did not work properly because of the attitude anomaly. The angular momentum kept accumulating in RW.【 Presumed Mechanism 2】

（4）Judging the satellite is in the critical situation, ACS switched to Safe Hold mode (SH), and the thrusters were used. At this time ACS provided atypical command to the thrusters by the inappropriate thruster control parameters. As a result, it thrusted in an unexpected manner, and it is estimated that the satellite rotation was accelerated.【 Presumed Mechanism 3】

（5）Since the rotation speed of the satellite exceeded the designed speed, the satellites parts that are vulnerable to the rotation such as solar array paddles (SAP), Extensible Optical Bench (EOB) and others separated off from the satellite.【 Presumed Mechanism 4】

(*)Unloading：Operation to decrease the momentum kept in RW within the range of designed range.

2. Presumed Mechanism from "Normal Status" to "Objects Separation"



MSP: JAXA Maspalomas station
MGN: JAXA Mingenew station

* IRU : Inertial Reference Unit

**The attitude control system in ASTRO-H is not using the sun sensor to determine satellite attitude. The system uses the estimated value calculated by the attitude control software.

Time in this page is expressed March 26 ,JST.

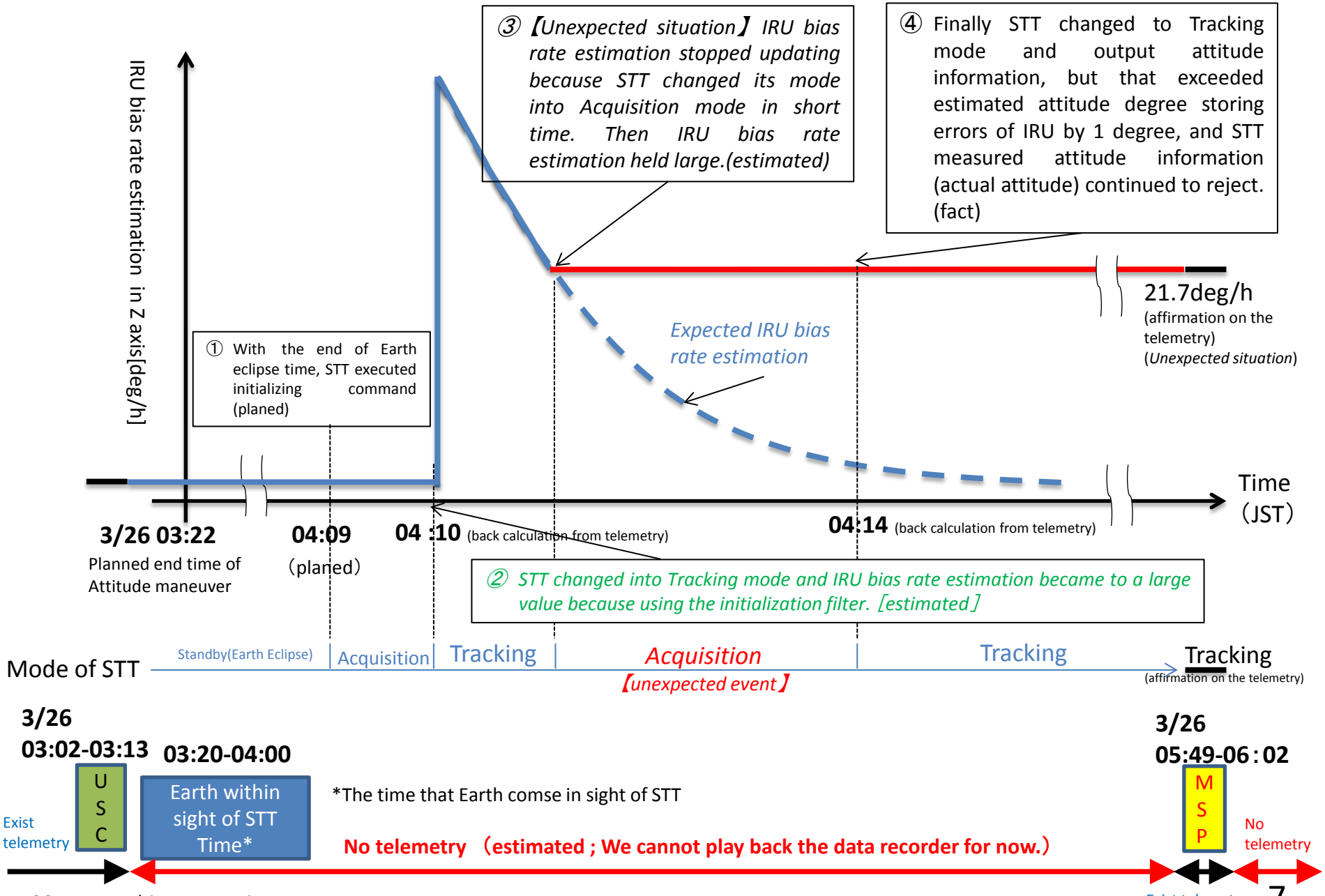
2. Presumed Mechanism from “Normal Status” to “Objects Separation”

*Supplemental information in P11

Presumed Mechanism 1 : From “Normal Status” to “Attitude Anomaly”

- ASTRO-H controls its own attitude using 2 instruments, Inertial Reference Unit (IRU) and Star Tracker (STT), at normal time.
- After the attitude maneuver operation was completed, ASTRO-H started using STT output data. At that time IRU bias rate estimation* becomes larger than actual one. After that by the correction using STT data, the value converges within normal one.
- There is a possibility that after the end of the attitude maneuver operation on March 26, STT output data had not been uploaded to ASTRO-H for some reason, IRU bias rate estimation remains larger and continued showing anomalous value.
- In this case ACS of ASTRO-H did not use STT output data, and determined the attitude only using IRU. So it is estimated that the attitude was controlled based on the false determination value of attitude.
  - ACS of ASTRO-H is designed so that the attitude will controlled only by IRU without loaded STT output data, if the difference between IRU estimated attitude and STT estimated value is larger than 1[deg].
- From the fact that IRU bias rate estimation mainly around Z axis continuously showed 21.7[deg/h], it is estimated that attitude control system controlled the attitude to counteract the estimated value with the rotate motion about 21.7[deg/h] around Z axis, then ASTRO-H started rotating.
- By the further analysis of the telemetry received at MSP and MGN, JAXA confirmed that ASTRO-H was rotating around Z axis about 20 [deg/h]

2. Presumed mechanism from the “Normal Status” to “Objects separation”



2. Presumed Mechanism from “Normal Status” to “Objects Separation”

Presumed Mechanism 2 : From the attitude anomaly to the continuously rotation of attitude

- As shown in the presumed mechanism 1, it is estimated that ASTRO-H made incorrect determination of its attitude as rotating, although the satellite was not rotating actually. In the result, the Reaction Wheel (RW) to stop the rotation was activated and lead to the rotation of satellite.
- On the other hand, the ACS does not use the sun sensor to determine its attitude, and anomaly was not able to be detected. As the result, the rotation continued.
  - The ACS is designed to detect its attitude anomaly by estimated value calculated by the system software. A sun sensor is not used for this purpose.
- At this time, it is presumed that the unloading process of angular momentum in RW by Magnetic Torquer operating in parallel to the rotation control did not work properly because of the attitude anomaly, then angular momentum was accumulated in RW.

- It is confirmed that, by the further analysis of the telemetry data of MGN at 09:50-10:04, the angular momentum in RW was rising near the design limitation (Telemetry 112[Nms], Limitation: 120[Nms])

Presumed mechanism 3 : From the attitude rotation to the rotation anomaly

- When exceeding the angular momentum limitation (120 Nms) accumulated in the RW, the ACS concluded that there was anomaly in the control by the RW, then shifted to a mode that controls its attitude using thrusters (Thruster Safe Hold Mode: RCS(Reaction Control System) SH(Safe Hold)).
- In the RCS SH, the satellite conducts the attitude recovery operation using thrusters by detecting the Sun, but it is estimated that there was injection control anomaly with inappropriate RCS control parameter.
- As the result, the velocity of the rotation increased.
- The sequence of events to set the RCS control parameter:
  - Feb 17, by pre-launch RCS control parameter setting, the Sun acquisition control using the thruster right after the launch was conducted normally.
  - Feb 28, JAXA sent the commands to update the RCS control parameter based on the center of mass changes by deployment of the EOB.
  - Through the post-incident investigation, it is confirmed the RCS control parameter on Feb 28th was not appropriate. This indicates the possibility of insufficient verification of the process from creating the parameter to setting it on the satellite. This situation is under investigation.
  - It is confirmed that the satellite had not been controlled by the thruster after resetting RCS control parameters on Feb 28.

Presumed mechanism 4 : From attitude rotation anomaly to the object separation

- As the result of increase in rotation speed, parts which are vulnerable to the rotation, such as SAP, EOB and so on, might break up and separate off from the satellite main body.

3. Presumed current status of ASTRO-H

- The main body of the satellite is spinning fast.
- Some parts which are vulnerable to the rotation, such as SAP, EOB and so on, might break up and separate off from the main body.
- Low battery (Communication recovery is necessary to receive the command to activate the battery charging function.)
- The communication with the satellite cannot be established. (since March 28)
  *The radio waves were received three times from ASTRO-H during 3/26 to 3/28, but the telemetry data were not obtained.
  JAXA continues the investigation to estimate the satellite status and recover its operation. Through the investigation, JAXA has recognized the following situation.
  - －Carrier frequency has been shifted to about 200 kHz from normal.
  - －Frequency spectral is different from the result of ground test.
- Decreasing the amount of Helium in Soft X-ray Imager(SXS) refrigerator.（JAXA estimates that it is not depleted for now (as of April 15th）.

4. The Near Future Plans

JAXA is going to work through the following tasks in parallel.

(1) Operation to re-establish communication and recover the power. Ground observations to estimate the status of the satellite such as rotation speed, the shape of ASTRO-H, etc...

(2) Verification of remaining estimations such as certain mechanism, Fault Tree Analysis(FTA) and others.

(3) Analysis on the background factors of this event including designing and development processes, operation and framework.

(4) Report to the Space Development and Utilization Subcommittee

Concluded

（Appendix）IRU Bias Rate Estimation

- IRU: a sensor to measure angular velocity [deg/sec] of a satellite along each axis(X, Y, and Z-axis)
- IRU values are integrated to determine the attitude of the satellite in the case of IRU only estimation,
  ex.)　measurement：0.1[deg/sec],　estimated attitude after 10 sec: 0.1×10[sec]=1.0[deg]）.
- The slight offset errors in the measured angular velocity are accumulated by the time integration.
  ex.)　Error in the measurement：0.01[deg/sec]　Attitude error after 10 sec：0.01×10=0.1deg）
- Comparing the attitude estimation with the STT of higher accuracy, the error trend of the IRU (shown in the orange line in the lower figure) is derived
- This error trend (the bias rate estimation)　enables us to estimate the satellite's attitude accurately even if the STT data are not available.

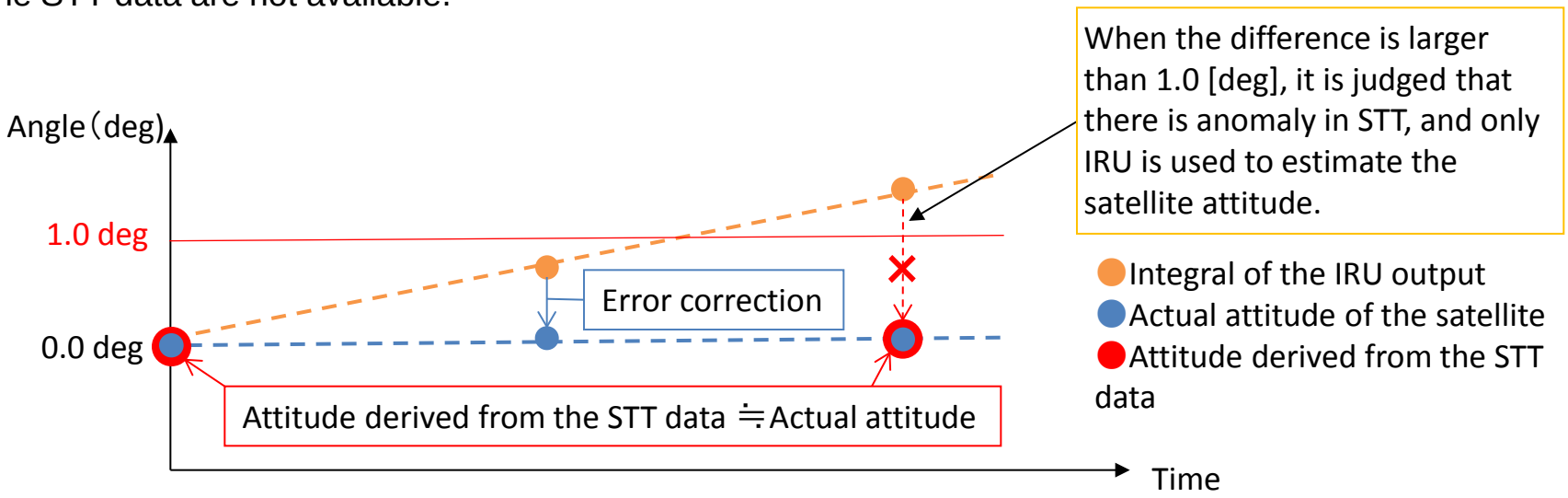


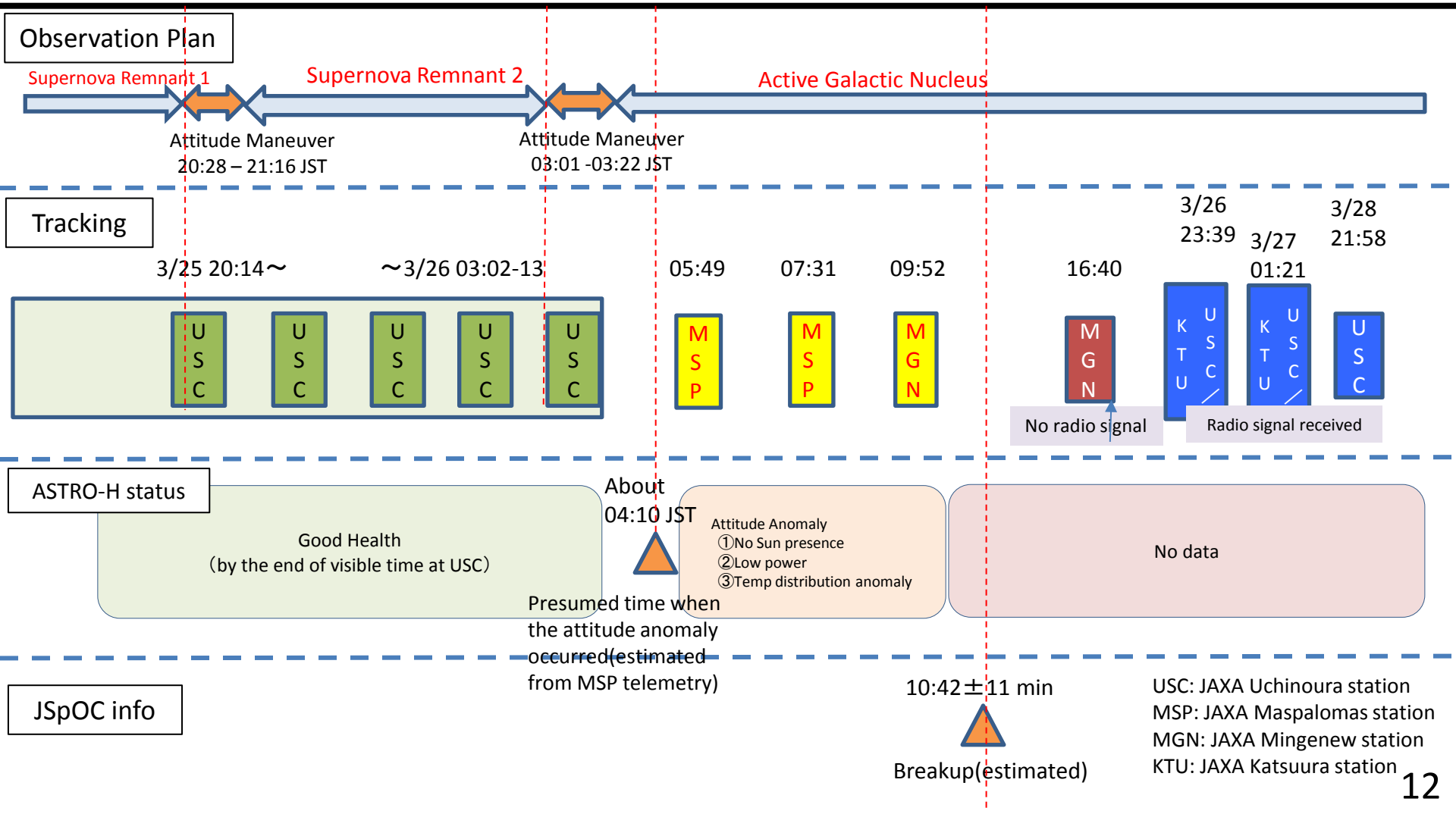
Figure : the sketch of the process.

※STT: Optical device to estimate the attitude of a satellite based on stellar positions.　A series of complicated calculation is required to derive the attitude from the STT data, and the frequency of its output is low. Contrary, the IRU 's output is speedy, because the derivation method of the attitude is simple.

（note）This is just a image to understand easily. This image differs from actual process.

【Appendix】Hitomi Sequence of Events

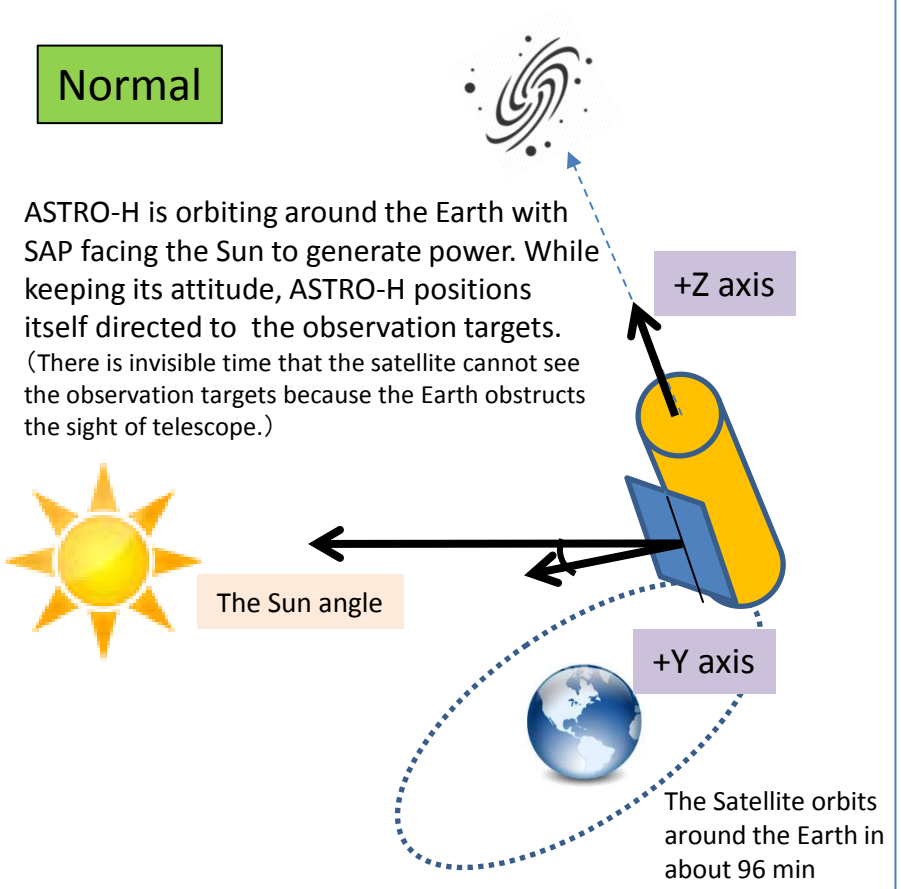
- The chart below shows a time sequence for the observation plan, satellite tracking, satellite condition on each events, and JSpOC information.



【Appendix】
Schematic of ASTRO-H behavior under attitude anomaly

Normal

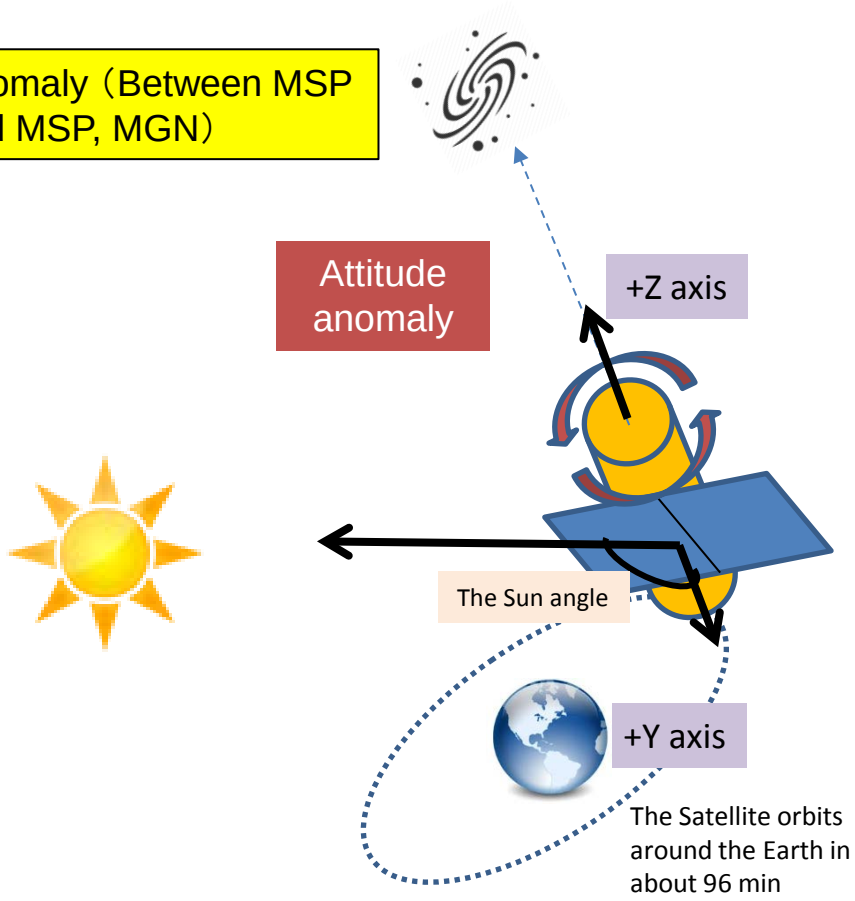
ASTRO-H is orbiting around the Earth with SAP facing the Sun to generate power. While keeping its attitude, ASTRO-H positions itself directed to the observation targets.
（There is invisible time that the satellite cannot see the observation targets because the Earth obstructs the sight of telescope.）



The nominal angle between satellite +Y axis and the Sun angle is within ±30 degrees.

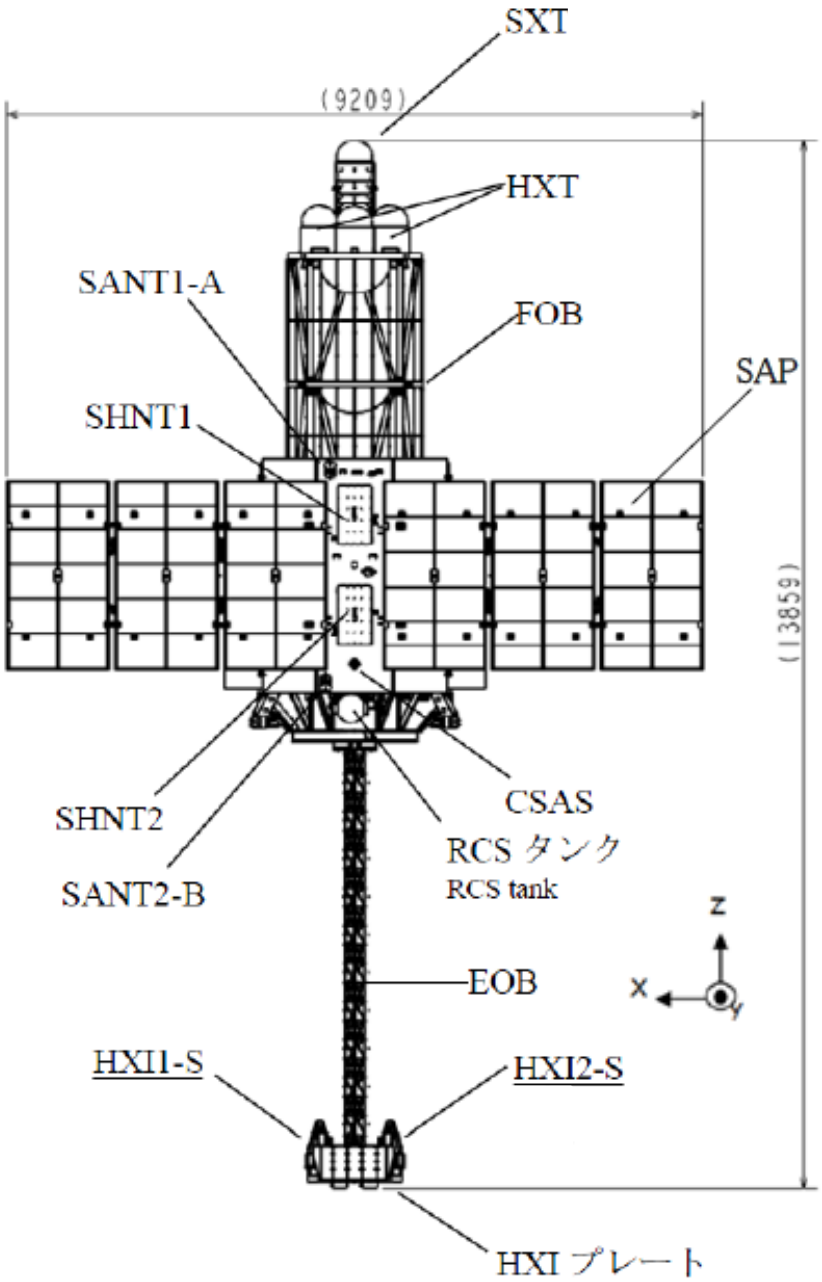
Anomaly（Between MSP and MSP, MGN）

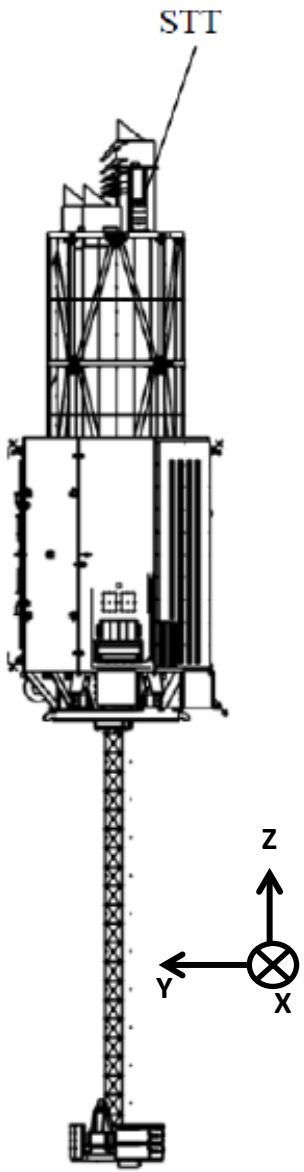
Attitude anomaly



The IRU estimated error value continues, and ASTRO-H began to rotate along Z axis about 21.7 degree/hour slowly. The Sun angle at a time of the last telemetry reception at MGN was about 123 degrees.

【Appendix】Exterior view of ASTRO-H





abbreviation	Name
SXT	Soft X-ray telescope
HXT	Hard X-ray telescope
SANT	S-band Antenna
FOB	Fixed Optical Bench
SHNT	Shunt Dissipater
SAP	Solar Array Paddle
CSAS	Coarse Sun Aspect Sensor
RCS	Reaction Control System
EOB	Extensible Optical Bench
HXI	Hard X-ray Imager
STT	Star Tracker

(Appendix)
The reentry prediction information of ASTRO-H objects

- **Reentry prediction information**

  Joint Space Operations Center (JSpOC) has released the trajectory information of 11 objects separated from ASTRO-H including the main body. The information provides reentry prediction of 2 (ID: 41438 and 41443) of the 11 objects in the webpage. According to the observation, these 2 objects started lower their altitude compared with other 9 objects.

  Predicted Dates

  41443 : April 29th, 2016

  41438 : May 10th, 2016

- **Reentry objects**

  JAXA estimates that these 2 objects will burn out in the atmosphere.