Supplemental Handout on the Operation Plan of the X-ray Astronomy Satellite ASTRO-H (Hitomi)

April 28th, 2016

JAXA

Time in this material is expressed in JST

Purpose of This Handout

This handout supplements technical details of the press release published on April 28th, 2016.

(1) Separation of the Solar Array Paddles (SAP)

(2) Radio signals that were presumed to come from ASTRO-H

(1) Separation of the Solar Array Paddles (SAPs)

- As the result of increase in rotation speed, the satellite parts that tend to be affected by big load caused by rotation, such as SAP, EOB and so on, had broken up and separated off from the satellite main body.
- Detailed simulations virtually assured the process to the rotation anomaly (Refer to Appendix).
- At the same time, investigation was conducted to determine the separation mechanism of the parts that tend to be affected by big load caused by rotation. It is likely that both SAPs had broken off at their bases instead of partial break off.
  - Detailed analysis (structural analysis based on finite element method) showed that the most affected part to big load by fast rotation was the peripheral areas of SAP bases.
  - The estimated spin rate that leads the break-up of the bases of SAP was consistent with those derived from the analysis of ground-based observations.

(2) Radio Signals Presumed to Come from ASTRO-H

- JAXA has reported the reception of radio signals that are presumed to be from ASTRO-H three times after object separation.
  - ① 23:49-23:52(3 min.), Mar. 26@USC, 23:48-23:51(3min.), Mar. 26@KTU
  - ② 01:23-01:27(4 min.), Mar.27@USC, 01:21-01:27(6 min.)@KTU
  - ③ 22:06 (10 sec), Mar. 28@USC
- Meanwhile, JAXA also recognized the following facts on these signal reception. Therefore, JAXA continued further detailed investigation.
  - Frequency difference of 200 [kHz] (Original carrier frequency: around 2.3 [GHz] / Received signal: 2.3002[GHz])
  - Frequency spectra were different from those received before the communication anomaly.
- Judging from the following points, it was believed the signals were from ASTRO-H:
  - The signals were received from the direction and time as planned.
  - The frequency shift would be possible by considering the condition under the unexpected status of the satellite.
  - The frequency information by ITU (International Telecommunication Union) showed no information of satellite that would cause possible interference

- Careful inspections of the design and obtained data by the ground tests of telecom system indicated as follows:
  - The attitude anomaly and temperature should not result in such carrier frequency shift of 200 [kHz].
- JAXA confirmed that there was another satellite that transmitted radio signals with similar characteristics to ASTRO-H.
  - JAXA received weak signals on April 13th during recovery operation of ASTRO-H. The signals were similar to the frequency spectrum detected on March 26th, but the detection was 2 minutes earlier than the scheduled time.
  - Assuming there is another satellite not registered in ITU, JAXA calculated its orbit and analyzed the Doppler frequency. The results were consistent with the radio frequency received on March 26th and 27th.
- Existence of the satellite with the similar frequency with 200 [kHz] shift w.r.t. ASTRO-H is confirmed. It is concluded all three radio signals were NOT from ASTRO-H.

（Appendix）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】

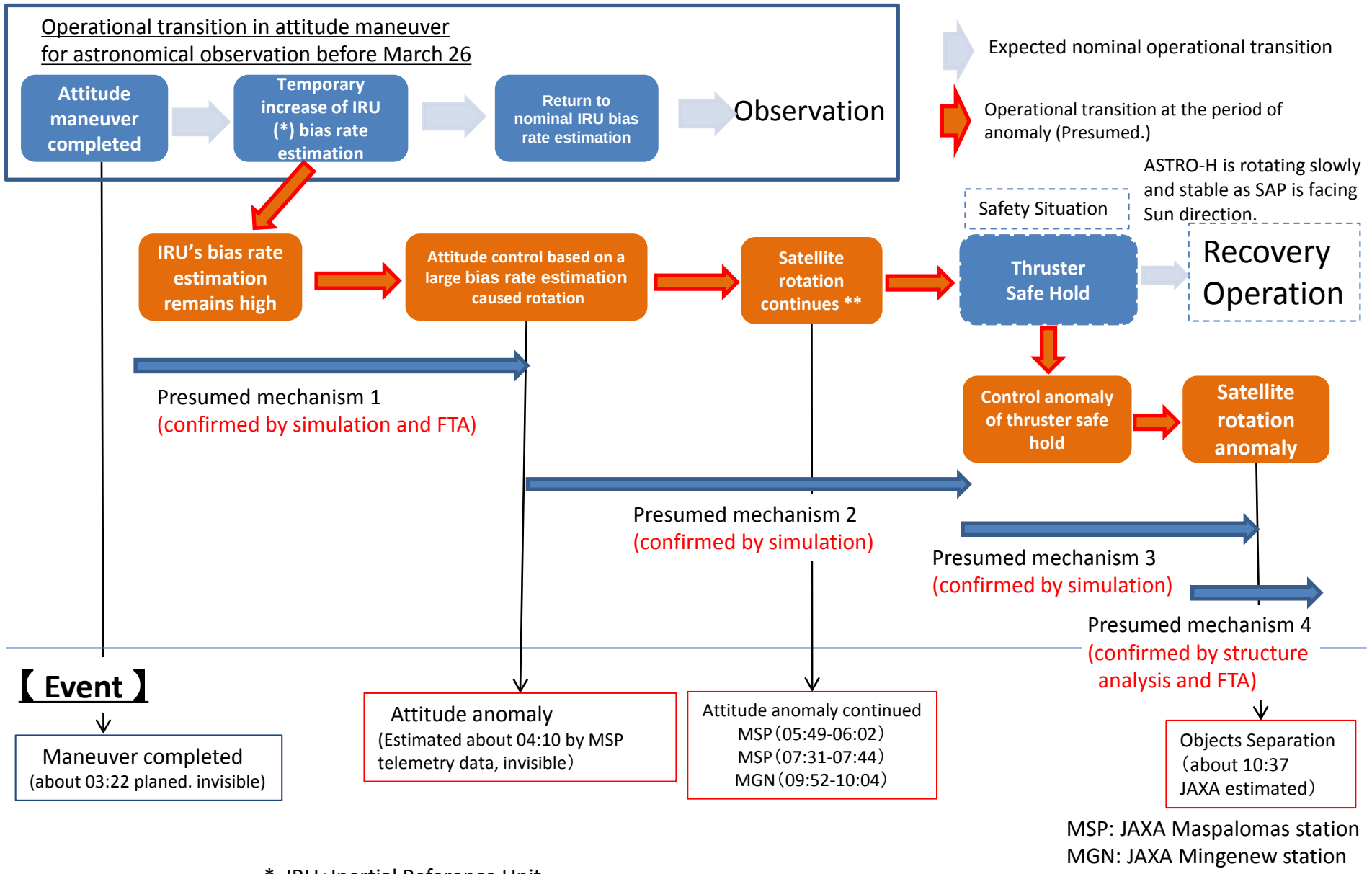
(3)In addition, unloading(*) of angular velocity by Magnetic Torquer operated by ACS did not work properly because of the attitude anomaly. The angular momentum kept accumulating in RW.【 Presumed Mechanism 2】

（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, parts of the satellite that are vulnerable to the rotation such as solar array paddles (SAPs), Extensible Optical Bench (EOB) and others separated off from the satellite. There is high possibility that the both SAPs had broken off at their bases and were separated.【 Presumed Mechanism 4】

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

(Appendix) Presumed Mechanism from "Normal Status" to "Objects Separation"



* 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.

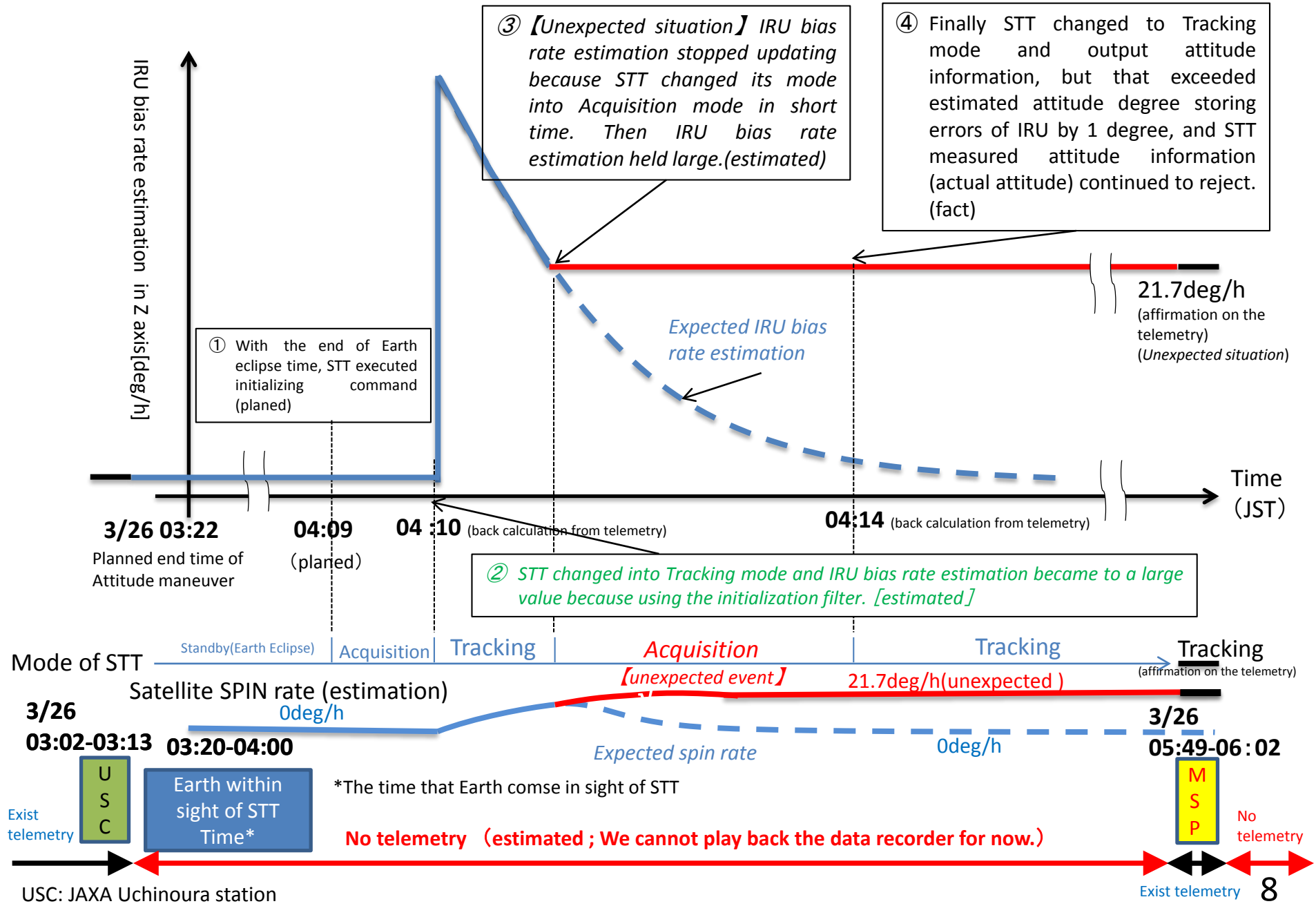
Time in this page is expressed March 26 ,JST.

（Appendix）Presumed Mechanism from “Normal Status” to “Objects Separation”

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

- ASTRO-H attitude control is based on 2 instruments, Inertial Reference Unit (IRU) and Star Tracker (STT), at normal time.
- After the attitude maneuver operation was completed, ASTRO-H was scheduled to restart using STT output data. At the time of restart, IRU bias rate estimation* becomes larger than the actual one. It was expected that the correction using STT data would converge value into normal range.
- 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, resulting IRU bias rate estimation to remain larger and to continue showing anomalous value, 21.7[deg/h].
- 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 the satellite.
- JAXA investigated the cause for IRU rate bias to remain larger by simulation based on STT mode change using on-board software. It was confirmed that the STT behavior as shown in Page 8, made IRU bias rate remain high.
- Conducting the FTA on IRU bias rate estimation anomaly, JAXA concluded there was a very little possibility for IRU sensor anomaly and ACS computer anomaly.

(Appendix) Presumed mechanism from the “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, ASTRO-H made incorrect determination of its attitude as rotating, although the satellite was not rotating actually. ACS does not use the sun sensor to determine its attitude, and anomaly was not able to be detected. As a result, the rotation continued.
- At this time, it is confirmed 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])
- JAXA estimated the accumulated angular momentum in case of attitude anomaly by computer simulation. Then it is confirmed that the estimated angular momentum was almost the same as the telemetry data.

(*)Unloading：Operation to decrease the momentum kept in RW within the range of designed range.
(**) accumulated angular momentum : correspond to the increase of the number of RW rotation

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
- There was injection control anomaly with inappropriate RCS control parameter. As a result, the velocity of the rotation increased.
- JAXA conducted simulation study on RCS behavior by using inappropriate RCS control parameter. The simulation showed the rotation acceleration behavior and the rotation speed finally went up to induce the break-up of SAP.

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

- As the result of increase in rotation speed, it is assumed that the parts which are affected by big load caused by rotation, such as SAP, EOB and so on, have broken up and separate off from the satellite main body.
- The rotation speed of ASTRO-H estimated by the ground observation and the calculated speed based on the structure analysis to be broken-up are on the same order. JAXA concluded it is likely that both SAP had broken off at their bases and were separated from the satellite.

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

- **Reentry prediction and reported information**

  Joint Space Operations Center (JSpOC) has released the trajectory information of 11 objects separated from ASTRO-H including the main body. The reentry prediction of 2 (ID: 41438 and 41443) of the 11 objects are shown in the webpage. The observation showed these 2 objects lower their altitude faster than the other 9 objects.

  – Reported Reentry

  41443： April 20^{h}, 2016

  – Predicted Reentry Date

  41438： April 28th, 2016

- **Reentry objects**

  It is estimated that these 2 objects should burn out in the atmosphere.