Solar-C Plan-B mission

System requirements on ultra-high data rate telemetry and scientific operations

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Scientific requirements to be considered in designing the telemetry and operation related system

The following top-level requirements shall be considered in the system design.

1. Continuous observations as long as possible
2. High-speed telemetry rate for plan-B telescopes
3. Scientific operations can be conducted like ground-based telescopes

Each topics will be discussed in next pages.

1. Continuous observations

- A “sun-synchronous” polar orbit has provided continuous viewing of the Sun for 9 months of a years.
  - “Hinode” takes this orbit.
- Geo-synchronous or equivalent orbit is another candidate.
  - SDO will take this orbit.
  - Eclipse seasons for 1-1.5 months, once per day.

2. High speed telemetry required

- A 0-th order estimate on the amount of data outputs from onboard telescopes by Dr. Katsukawa
- One of key scientific capabilities is to acquire spectro-scopic or spectro-polarimetric data with highest possible cadence. This requirement requires high speed telemetry capability.

	Visible-UV Telescope		EUV Spectrometer	
	Average obs.	Burst obs.	Average obs.	Burst obs.
Raw data (pixel/sec)	1.8M	18M	102K	1M
Compressed (bits/sec)	9.4M	94M	0.5M	5M

(assumed 5-7bits/pixel lossless compression here)

- Will expect data flow with rate smaller than 10Mbps for average observations
- Will need the capability for performing burst observations by the Visible-UV telescope, which is expected to produce ~100Mbps data flow.

Visible-UV Telescope Data Estimate

- Average observations

Examples	Slit polarimetric obs, high S/N, low rate		Imaging obs, low rate	
Image products	2048(spatial)x256(λ)x4(pol.)		2048x2048 at 4λ	
Cadence	10 sec for one position		10 sec for one set	
Raw data flow	2048x256x4/10= 0.2M pix/s (3.2Mbps)		2048x2048x4/10= 1.6M pix/s (41Mbps)	
Compression	Lossless, 7bits/pix	Lossy, 2bits/pix	Lossless, 5bits/pix	Lossy, 2bits/pix
Data flow	1.4Mbps	0.4Mbps	8.0Mbps	3.2Mbps

- Burst observations

Examples	Slit polarimetric obs, low S/N, high rate		Imaging obs, high rate	
Image products	2048(spatial)x256(λ)x4(pol.)		4096x4096 at 10λ (1A/100mA)	
Cadence	1 sec for one position		10 sec for one set	
Raw data flow	2048x256x4/1= 2M pix/s (32Mbps)		4096x4096x10/10= 16M pix/s (256Mbps)	
Compression	Lossless, 7bits/pix	Lossy, 2bits/pix	Lossless, 5bits/pix	Lossy, 2bits/pix
Data flow	14Mbps	4Mbps	80Mbps	32Mbps

EUV Spectrometer Data Estimate

Examples	Slit spectroscopic obs high S/N, low rate		Slit spectroscopic obs low S/N, high rate	
Image products	2048(spatial)x512(λ)		2048(spatial)x512(λ)	
Cadence	10 sec for one position		1 sec for one position	
Raw data flow	2048x512/10= 0.1M pix/s (1.2Mbps)		2048x512/1= 1M pix/s (12Mbps)	
Compression	Lossless, 5bits/pix	Lossy, 2bits/pix	Lossless, 5bits/pix	Lossy, 2bits/pix
Data flow	0.5Mbps	0.2Mbps	5Mbps	2Mbps

This 0-th estimate is a good start point for plan B mission?

3. Onboard data processing (1/2)

- Image compression is probably required on board.
- For the visible-UV telescope, 18M pixel/s raw data flow may be converted to 94Mbps or less compressed data flow.
- A deep consideration will be needed to realize the real-time (JPEG) compression on board.
  - Assuming that a compression scheme needs 10 operations per 1 pixel, the CPU with 100MIPS performance can process in the real time the data flow with up to 10M pixel/sec. This means a faster processor or a hardwire consideration will be required.

3. Onboard data processing (2/2)

- Space Wire will be the standard I/F line between components in the ISAS future satellites.
  - The first ISAS satellite with Space Wire I/F is BepiColombo MMO. The current performance in the laboratory is 50~100Mbps.
  - With a multiple number of lines in parallel, the data speed can be increased to a multiple of 50~100 Mbps.
  - The transfer of ~18M pixel/s raw data and ~100 Mbps compressed data would have reality with Space Wire.

4. Orbit and Communication Band (1/3)

- Sun-synchronous polar vs. Geo-synchronous as candidate
- Sun-synchronous polar orbit
  - Short duration (~10 min) at each station contact.
  - Need a large number of station contacts and high telemetry downlink speed
    - ~100Mbps is required when 15 contacts per day (150min in total).
    - This speed allows to perform observations with ~10Mbps on average.
  - K-band needs to be explored for high speed downlink.
    - X-band usage has ~10Mbps upper limit (SFCG recommendation) because 100Mbps transfer occupies wide (greater than 10MHz) bandwidth.
    - New area for JAXA and need new ground station facilities
    - K-band is not yet used at Svalbard, although a future plan exists.
    - Ka (37-38GH) communication is easily affected by weather condition (rain falls), giving complicated operation.
    - Deep negotiation will be needed for frequency allocation.

4. Orbit and Communication Band (2/3)

- Geo-synchronous orbit
  - Continuous communication link with the spacecraft for 24 hours, if a dedicated antenna is newly prepared.
  - With the 24hr continuous downlink, X-band is a strong candidate.
    - X-band downlink is ~10Mbps upper limit (SFCG recommendation)
    - If higher speed is really required from science, we also need to explore K-band usage (Ku-band?), which is a new area for ISAS and needs a new ground facility.
  - A dedicated antenna is required.
    - Only for downlink purpose?

      Cheap. USC and JAXA NGN antenna are used for uplink.
    - Should also have uplink capability? Expensive

4. Orbit and Communication Band (3/3)

- S-band can be used for commanding and housekeeping telemetry.
  - New S-band transponder will be available with 256Kbps uplink and up to 2Mbps downlink for Astro-H and ISAS satellites.

5. Operate like ground-based telescopes (1/5)

- Hinode's scientific operation planning
  - Observations including observing sequence and pointing schedule are planned in the previous day of the command uplinks.
  - Minor pointing adjustment may be made 7~8 hours before the start of the OP timeline.
- It is difficult to take quick actions for capturing activities and dynamical changes always occuring on the Sun.
- For the plan B mission, one of key scientific observations is spectro-scopic or spectro-polarimetric observations.
  - Scanning with a narrow slit takes a fairly long duration to cover a wide field of view, although high throughput telescopes will be considered.
  - Good capturing the events of interest with spectroscopic observations would much increase scientific returns.
  - Good capturing is extremely important for studying dynamics and activities on the Sun.

5. Operate like ground-based telescopes (2/5)

- Autonomous functions for capturing small activities, such as flux emergence, are not easily designed.
  - Most reliable method is that scientists in the operation room select the observing target, by real-time monitoring some latest images from the telescope.
- Such an environment should be prepared for the plan B.
  - 10~15 min timescale may be a good design target.
    - The selection of target (pointing change) can be made 10~15 min before the start of an observation.
    - 10~15 min is the typical timescale of flux emergence.
  - Components needed to realize the environment.
    - Some latest images from the telescope can be displayed on a monitor in the operation room.
    - A user-friendly and easy capability for selecting the target.
    - A capability for generating and verifying the uplink commands.
    - Uplink connection for commanding to the telescope.

5. Operate like ground-based telescopes (3/5)

- Continuous downlink and uplink connection with the satellite on a geo-synchronous orbit is preferable for designing the environment.
- 24 hours connection may increase scientists working load and we may need an operation rule for performing real-time target selection.
- The ground support system needs to be well designed, so that it can provide more simple and easy planning.
  - Significant efforts should be given to the ground support system.
- Each telescope may need a capability to take different telescope pointing, because of simple observation coordination.

5. Operate like ground-based telescopes (4/5)

- No intelligent functions for performing observations may not be needed on board.
  - Hinode has Mission Data Processor (MDP), which provides observation tables with too intelligent functions for SOT and XRT.
  - The MDP observation tables look too complicated because of providing a large amount of freedom on observations.
  - The table function on board should be much simplified, or it may be partially located on the ground support system.

5. Operate like ground-based telescopes (5/5)

- Bus functions available in the ISAS future missions will be effectively utilized in the detailed design.
  - Commanding functions
    - A new “timeline” function, i.e., the list of command and UT time, which is different from OP/OG.
    - Command uplink speed will be significantly increased from 4Kbps to 256Kbps.
    - No memory dump is required for table memory upload. Instead, check-sum can be used for upload verification.
  - Quick-look data downlink (for sun-synchronous orbit)
    - Only two partitions are available in the Hinode’s DR.
    - A large number of DR partitions can be defined in DR. This capability may be useful to downlink the latest data with highest priority.

Summary

1. A geo-synchronous or equivalent orbit is more preferable for plan B, rather than a sun-synchronous polar orbit.
2. With a geo-synchronous orbit, ~10Mbps continuous downlink in X-band can be a candidate.
   – If sciences require very long continuous data flow with higher than10Mbps, we should explore K-band downlink.
3. High-speed telemetry rate for telescopes
   – <10Mbps for average and possible ~100Mbps burst obs
4. We should have capabilities to perform scientific operations like ground-based telescopes.
   - Quick selection of observing target
   - Easy and simple planning of observations