Chapter 5: Spacecraft and Mission Design

The spacecraft characteristics as the baseline are summarized in Table 5.1. Key items of the characteristics are described in following sections.

Table 5.1. Characteristics of the baseline spacecraft.

Spacecraft layout	Telescopes mounted on the optical bench, which is on the Bus module. See Figure 7.1.
Weight	4930 kg (at liftoff), 2330 kg (dry weight)
Size	3.2 m x 3.2 m x 7.4 m, excluding solar array paddles
Launch vehicle	JAXA H-IIA (type 202)
Orbit	An inclined geo-synchronous orbit (Baseline) A sun-synchronous polar orbit (optional)
Power	~3,500 W (maximum)
Command & Telemetry	Uplink and housekeeping downlink: S-band Downlink: X-band 16-QAM (16Mbps) Ka-band QPSK (80Mbps, optional)
Attitude control	3-axis body pointing with high accuracy Image stabilization system in some telescopes A function to change the pointing around Z-axis for matching spectrograph slit direction to the observing target.
Science operations	Hinode operation scheme, with a final target selection around 10 to 15 minutes before the uplink in cases where this is essential for the science.

Two candidates exist for the X-ray imaging telescope. Here we assume the photon-counting grazing-incidence telescope, because it will require larger size and mass and higher telemetry rate.

5.1. Spacecraft Layout

The layout concept of the Solar-C Plan-B spacecraft is shown in Figure 5.1. Technical heritage acquired with the development of the Hinode (Solar-B) spacecraft is used as much as possible, including the design concept of the spacecraft structural layout. The three telescopes are mounted with mounting legs on the spacecraft OBU (Optical Bench Unit), which is a CFRP-made cylindrical structure providing stable condition to the telescopes. The telescope portion of the UV-Visible-IR telescope (SUVIT) is equipped inside the OBU cylinder. Its focal plane instruments and the other two telescopes are mounted on the external wall of the OBU. The mounting legs are made from low-thermal expansion materials, and provide 6-axis freedom kinematic mount to the telescopes. The OBU is mounted on the spacecraft bus module with a truss structure in order to isolate the OBU and telescopes from the influence of the thermal deformation of the bus module.

It is important to minimize co-alignment changes among the three telescopes and the attitude sensors against the launch load and the in-flight thermal environment. The three telescopes and the attitude sensors (UFSS and IRU) are mounted on the same structural component, i.e., OBU, to achieve precise co-alignment among them.

The size and mass of the telescopes used for the initial design are listed in Table 5.2. The values in this table are the initial guess based on the aperture size and focal length currently under consideration for each telescope. The values contain significant uncertainty and will be revised as the design is in progress.

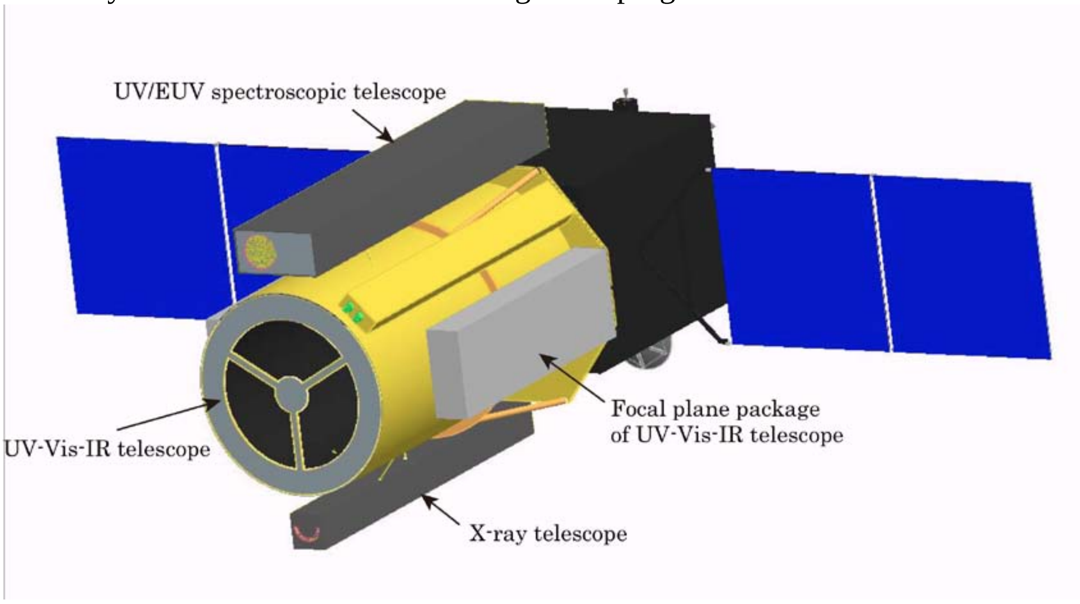

Figure 5.1. SOLAR-C plan-B spacecraft

Table 5.2. Size and weight of the telescopes used as the initial parameters.

Instruments		Size (mm)	Weight (kg)
UV-Vis-IR telescope	Telescope	φ2300 x 4300	500
	Spectrograph	1000 x 400 x 3200	100
	Imager	1000 x 400 x 3200	100
UV/EUV spectroscopic telescope		1000 x 500 x 5000	150
X-ray telescope (photon counting)		400 x 400 x 4500	150
Total			1000

The initial mass estimate result is shown in Table 5.3. The total mass of all the telescopes (1,000 kg) is a very rough value (upper-side value) and this will be revised as the telescope design is in progress. The spacecraft bus system is about 1,260 kg. The propellant for moving the spacecraft from a geo-transfer orbit (GTO) into an inclined geo-synchronous orbit (GEO) and maintaining the GEO orbit is counted as about 2,300 kg, which is the initial guess based on the information available on the website of Michibiki (QZSS), which has an inclined geo-synchronous orbit (GEO). The reasons why we are considering a GEO orbit as the primary option can be found later.

JAXA H-IIA 202 rocket is assumed as the baseline launch vehicle. This rocket is capable of installing a 4-ton spacecraft into a GTO orbit. The initial mass estimate shows about 500 kg over the 4-ton, and we will need to make efforts to reduce the mass by looking at the accuracy of mass estimates. Note that H-IIA 204 rocket, with four solid rocket boosters, can install a 6-ton spacecraft into a GTO orbit, although it is much more expensive.

Figure 5.2 shows the dimension of the spacecraft, which can be fitted in the Model-4S fairing envelopes. The height is about 7.4m. The front-end position of the X-ray and UV/EUV telescopes may be located much below the front position of the UV-Visible-IR telescope, if the 4S fairing is used. This may give a contamination risk to the UV/EUV and X-ray telescopes, because these telescopes entrance views the outer side surface of the UV-Visible-IR telescope. In the design phase, we should carefully evaluate this layout and contamination issue in order to minimize the contamination risk.

Table 5.3. Initial mass estimate result.

Components		Weight (kg)	Remarks
Mission instruments		1000	Table 7.2
Structures	Bus module	340	Based on a standard Bus module
	Optical Bench	70	Sizing from Hinode optical bench
Thermal control system		100	
Data handling (space wire) system		10	Based on Astro-H (space wire) system
Communication	S and X-band	21	Based on Section 7.2.3.
	Ka-band (optional)	TBD	
Electric power system		142	
Solar array paddles		120	2 wings, 2 panels for each wing.
Attitude & Orbit control system		100	Including MIB (momentum wheel isolation bench, 30kg)
Chemical propulsion system		170	Including apogee kick motor (~500N thruster, section 7.3)
Other peripheral hardware, such as electrical cables and mechanical parts		185	
Total (dry weight)		2258	
Propellant		2300	Based on the information available on the Michibiki (QZSS) website.
Total (at liftoff)		4558	

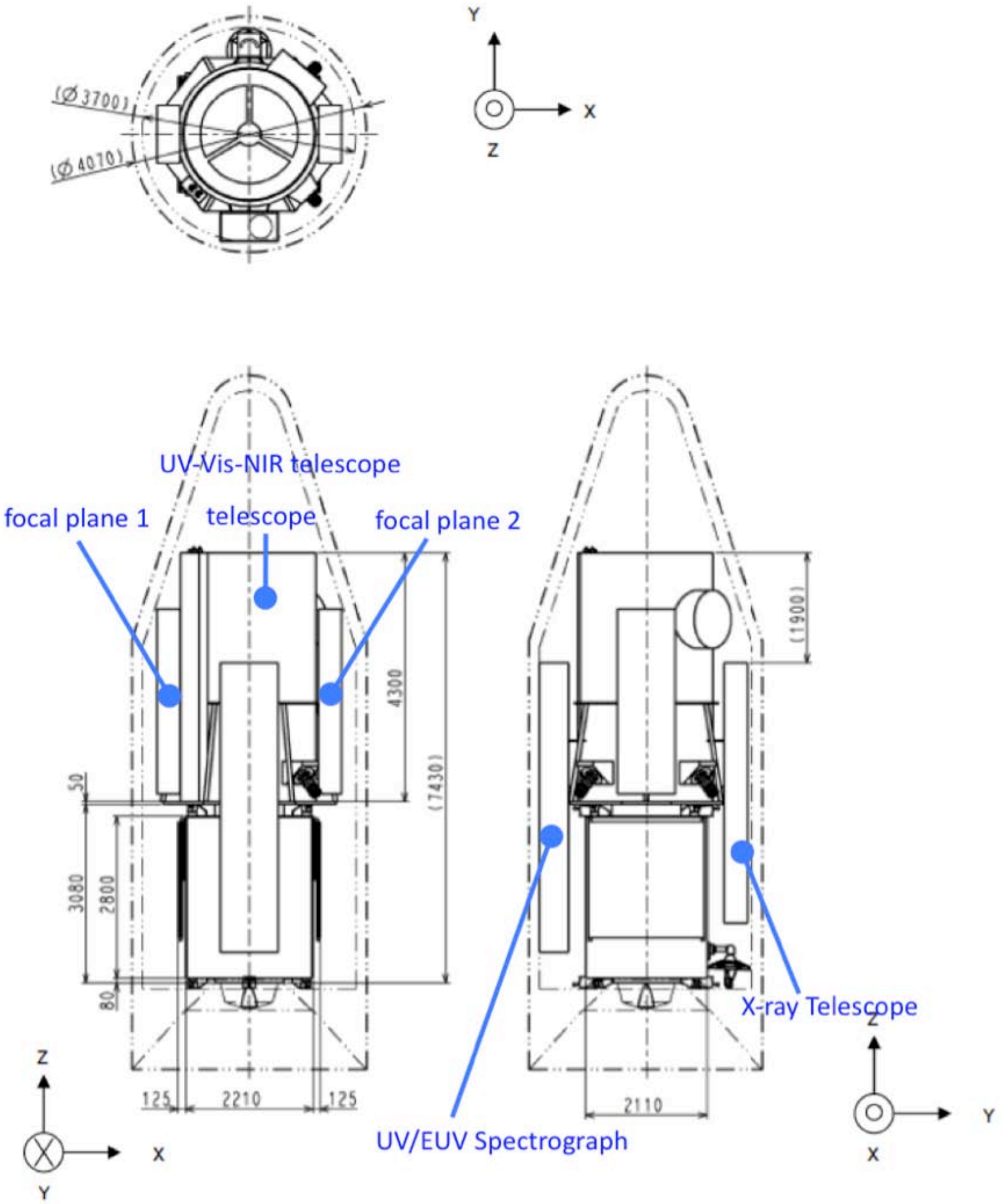

Figure 5.2. The spacecraft layout in the 4S fairing of the JAXA H-IIA rocket

5.2. Science Telemetry

5.2.1. Data rate estimate

Table 5.4 summarizes the data rates estimated from the three mission instruments. This is the initial guess based on the preliminary science design including the format size of detectors and typical exposure cadence. Details of the estimate can be found in Appendix 7-A. The table tells that high rate science telemetry is required to acquire spectroscopic and polarimetric data with high cadence and resolution. "Standard" case is for continuous observations without interruption, producing data with a constant rate. "Burst" case means that the data is produced with highest data rate, but the duration of such observations is limited.

The minimum requirement is that *the data can be acquired constantly with the data rate (the rate after compression) of about 8 Mbps in total*. According to evaluation of Hinode data, lossy compression is acceptable to most science cases, excepting X-ray telescope's photon counting data, although the effect from lossy compression needs to be evaluated in the future. Thus, we assume to apply lossy compression to the data.

Also, much higher rate needs to be handled on board to have burst case observations. Assuming lossy compression can be used for burst case, the data output with 570 Mbps (before compression) and 143 Mbps (after compression) should be handled properly on board.

Table 5.4. Estimated data output rates from the mission instruments.

Instruments		data rate (Mbps)		
		no comp.	lossless comp.	lossy comp.
Solar UV-Vis-IR telescope	standard	14.4	6.1	2.5
	burst	320	128	48
UV/EUV spectroscopic telescope	standard	7.0	3.0	1.5
	burst	140	60	30
X-ray telescope (photon counting)	standard	6.9	3.5	
	burst	110	55	
Total	standard	28.3	12.6	7.5
	burst	570	243	143

5.2.2. Data handling on board and data recorder

The overall flow of the science data on board is described in Figure 5.3. It is the baseline that data compression is performed in each telescope before producing the data into the spacecraft bus. Since different types of data products (imaging, spectroscopic, and photon counting) are generated in the three mission instruments, it would be good to use different compression algorithms more suitable for the properties of data products. After compressing and packetizing the data, each instrument sends compressed data to the spacecraft. SpaceWire may be used for the data interface between the telescopes and spacecraft. There is no mission data processor, which is different from Hinode science data handling system.

When we run continuous (i.e. 24 hours every day) observations with the 8Mbps data generation rate, *the total data amount is about 700 Gbits per day*. Since the maximum duration of the ground station support at USC may be less than 8 hours, the data needs to be recorded in the data recorder. The capacity of the data recorder should be enough to allow us to have continuous observations for 24 hours every day. Moreover, the data recorder allows us to run the burst observations; Data produced burstly is stored in the data recorder, followed by downloading the stored data after the acquisition when the spacecraft is linked to a ground station. The capacity of the data recorder will be determined by considering the observation plans and the capacity reality.

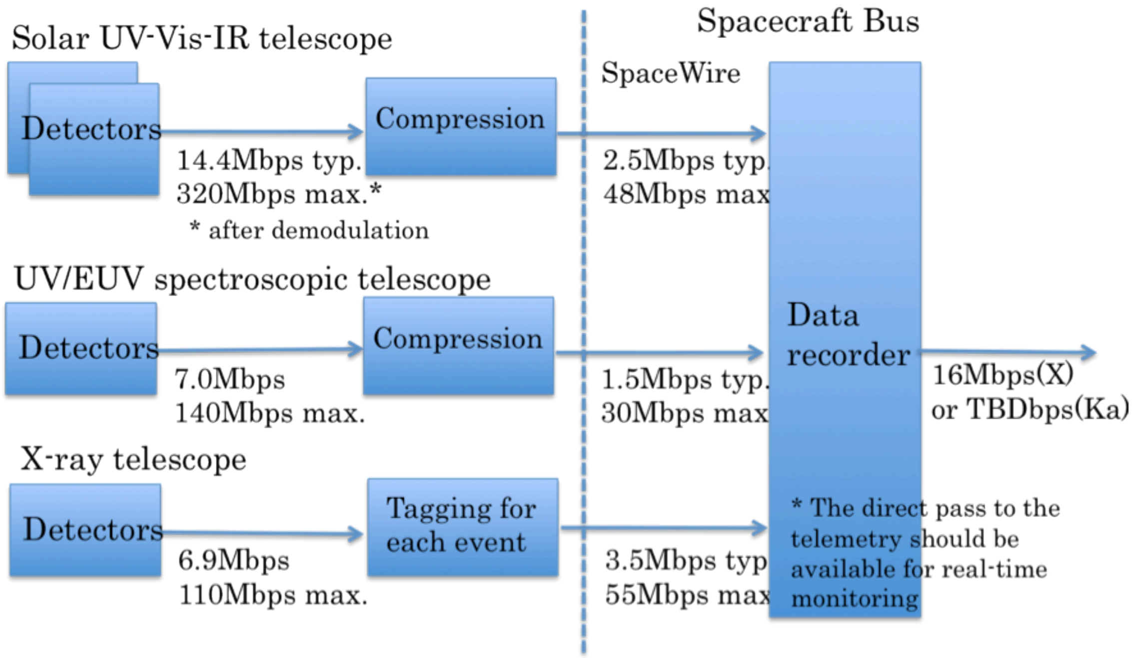

Figure 5.3. Overall data flow estimate

5.2.3. Science Telemetry System

The high-speed telemetry channel is absolutely required for the Solar-C Plan B mission to transfer the huge amount of data expected from the onboard telescopes. The requirement is to design the telemetry and data storage system to enable downloading the volume of the data produced constantly with the rate of about 8 Mbps.

An initial trade-off study suggests either an X-band telemetry system (16Mbps, 16-QAM modulation, with semi-directional low-gain antennas), or Ka-band telemetry system (80[TBD]Mbps, QPSK modulation, with directional high-gain parabola antenna), or the both of them. Each telemetry system is briefly described below.

X-band telemetry system (Figure 5.4)

X-band telemetry is easy to handle, but the problem is that the allowable bandwidth is restricted within 10MHz for near-earth space science applications in X-band frequency band, according to a recommendation by the ITU's SFCG (Space Frequency Coordination Group). If we use the QPSK (phase shift keying) modulation, same as Hinode's X-band modulator, the telemetry speed needs to be below about 8 Mbps to meet the signal bandwidth restriction. Instead, the 16-QAM (quadrature amplitude modulation), which is widely used on the ground communication and will be tested in one of Japanese technology demonstration satellites, can increase the telemetry speed to 16 Mbps.

If we have 12 hours for the telemetry downlink in total per day, the telemetry system can transfer all the data acquired with 8Mbps continuously for 24 hours. We assume USC 34m antenna as the primary antenna, and the system can be designed to have a positive link margin. Considering other spacecraft operations at USC 34m, the duration of downlink may be restricted below 8 hours. Thus it would be helpful to have additional downlinks on NASA and ESA stations, if antennas are available in Asia, Oceania, and Pacific Ocean area. It is also noted that a huge mass memory (recorder) is needed to record the data taken during non-contact period.

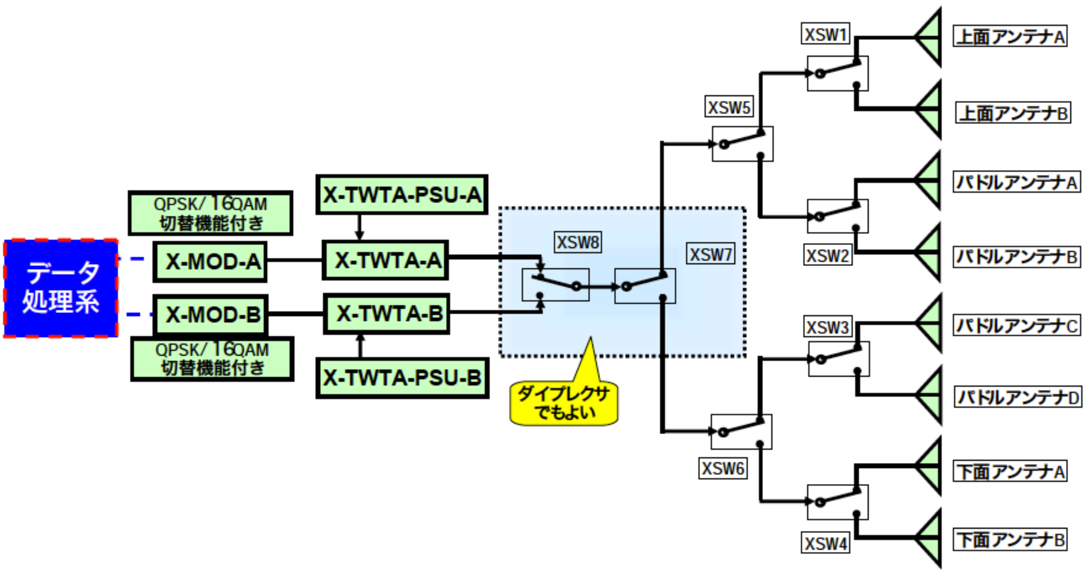

Figure 5.4. X-band telemetry system

Ka-band telemetry system

Another possibility is to newly explore the usage of Ka-band in Japan. Higher telemetry rate is possible because a wider bandwidth can be utilized in the Ka band by a spacecraft. Two candidate bands are identified; 1) ~17GHz, a portion of ground equipments available at USC can be used to minimize the cost. 2) ~26GHz, this band is used at the Near Earth Network (NEN) of NASA. It is needed to newly prepare the system for receiving signals at this band in Japan, if the telemetry is received at Japan. When the bandwidth is 100 MHz, 80 Mbps is achieved with QPSK. The downlink duration can be reduced to a few hours, although a more huge mass memory (recorder) is needed.

A concern is that attenuation of signals due to bad weather (rains and heavy clouds) in Japan affects quality of the data and gives complication to real-time daily operations.

The both X-band and Ka-band systems work in case of the GEO orbit; X-band 16-QAM (16Mbps) as a baseline and Ka-band QPSK (80Mbps) as an option, though we have to implement the Ka-band capability at a ground station. However, it is impossible to adapt the X-band system if the spacecraft is in a sun-synchronous polar orbit, because about 15 passes are too small to download all the data. The only way is to adapt the Ka-band system, but a Ka-band antenna is required in the polar region, such as at Svalbard. At least 144 minutes are needed as the total contact duration to download all the data with 80Mbps and this duration corresponds to about 12 station contacts. During each contact (duration ~ 12 minutes), the Ka-band high-gain antenna is quickly moved to direct to the ground station, resulting in a concern of micro-vibration from the antenna mount mechanism. More details of the downlink system for the GEO orbit are summarized below:

1. GEO/X-band (baseline)
   - The 16-QAM modulator, which is under development for the ASNARO mission
   - The bit rate is 16 Mbps, which occupies the band width ~10MHz
   - Semi-directional low-gain antenna (angle ~ 60°, 0dbi), which is used in HAYABUSA. At least 6 (TBD) antennas are mounted to cover any direction, one of which is selected by switch.
   - 50W TWTA amplifier, which is under development for the ASTRO-G mission.
   - The link margin is XXX dB for USC 34m.
   - It is necessary to implement the X-band 16-QAM demodulator at the USC.
2. GEO/Ka-band (optional)
   - The QPSK modulator and the bit rate is 80 Mbps (band width=100MHz)
   - φ 0.3m high-gain antenna (32dbi) + 0.5W SSPA, whose pointing is driven by a two-axis mount mechanism.
   - The link margin is XXX dB for USC 34m.
   - It is necessary to make the Ka-band (17GHz) at the USC available. Another possibility is to make use of Ka-band (26GHz) with NASA or ESA ground station.

5.3. Orbit

As briefly discussed in section 5.2.3, two orbit candidates are considered for the Plan B spacecraft. Currently, an inclined geo-synchronous orbit (GEO) is considered as the baseline, with a sun-synchronous polar orbit (SSO) as the backup.

<u>Geo-synchronous orbit (GEO):</u>

- Same as Solar Dynamic Observatory (NASA)

- Altitude: 36000km, inclination: <30°, period: 1 day

<u>Sun-synchronous polar orbit (SSO):</u>

- Same as Hinode, TRACE, and IRIS.
- Altitude: 680-800 km, inclination: 97-98°, period: 98 min

The GEO orbit would provide much more advantages than the SSO orbit, although a demerit on the weight of the spacecraft. Advantages are listed below:

- X-band telemetry can be utilized to download the data volume required for observations, though the duration of contacts is fairly long (8 hours or longer per day).
- Thermal environment is colder in GEO than in SSO because of lower influence of infrared radiation from the earth, which much helps the thermal design of the optical telescope (see section 4.3.4).
- GEO is thermally very stable, providing less orbital variation of thermal environment. This would reduce structural deformation, resulting in less orbital variation in pointing stability (section 5.4.1) and temperature fluctuation of telescope optics.
- A new type of methodology for science operations (section 5.7) can be adapted, which would much help the narrow field-of-view spectroscopic telescopes to perform optimized observations
- Eclipse seasons are shorter in GEO than in SSO. SSO has eclipse season with about 20 mins (at maximum) duration every 98 mins orbital period and the season continues three months every year. The GEO's eclipse is about 72 mins (at maximum) duration per day and it continues only one month, twice every year (see Figure 5.5). A potential demerit is to need a large capacity of the battery for keeping some components warm without solar heat input.

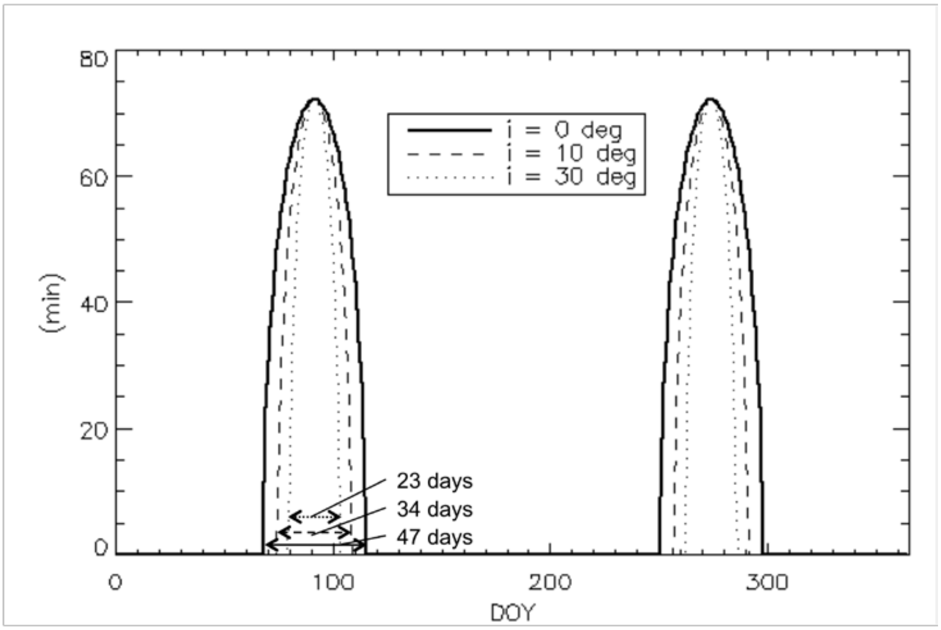

Figure 5.5. Eclipse duration in the case of GEO. The maximum duration is 72 mins per day. The eclipse season happens twice every year around the equinox. The duration of

the eclipse season depends on the inclination angle of the orbit.

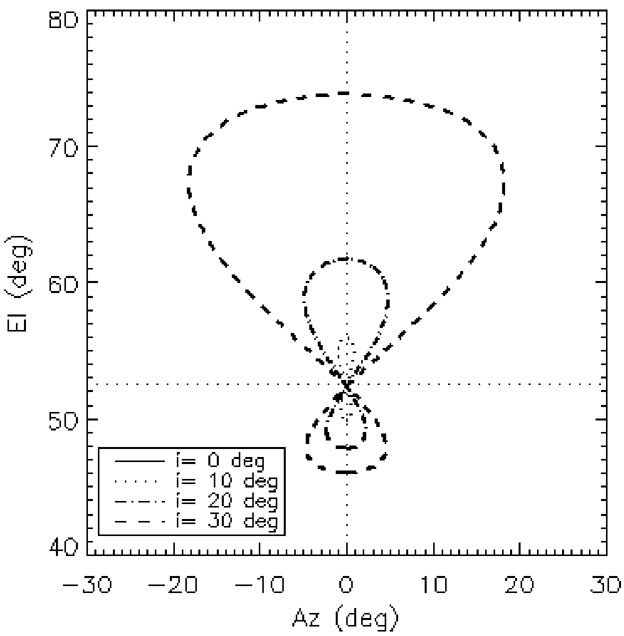

Figure 5.5: Visibility of the spacecraft from USC that is located at latitude of 30°N when the spacecraft is in GEO with inclinations.

It is not necessary to install the spacecraft into the geostationary orbit (GSO) in which the spacecraft is located directly above the equator where the inclination angle is 0°. When the orbit is at non-zero inclination, the duration of the eclipse season can be made shorter than one month (Figure 5.5). The spacecraft is no longer stationary when viewed from a ground station at the non-zero inclination. The spacecraft is always visible at an elevation angle higher than 45° at USC (latitude 31°N) when the inclination angle is less than 30° (Figure 5.6), which is high enough for continuous contact without interruption.

The most critical issue of GEO is that an apogee kick motor is required to install the spacecraft from GTO to GEO. The engine and its propellant take half of the total weight at the lift-off as is shown in Table 5.3.

5.4. Pointing Stability and Attitude Control

5.4.1. Requirements on the pointing stability

We set targets of angular resolution better than 0.1 arcsec in the Solar Ultraviolet-Visible-IR telescope, and better than 0.2 - 0.5 arcsec in the UV/EUV and X-ray telescopes. The angular resolution requires high stability of the body pointing, otherwise images are blurred due to residual pointing jitter. The requirements on the pointing stability are thus derived based on the requirements on the angular resolution and exposure duration to obtain a data set (an image or set of images), and are summarized in Table 5.5. In Figure 5.7, the requirements on the pointing stability for both HINODE and SOLAR-C are indicated and compared as a function of frequency.

Table 5.5. Requirements on the pointing stability of the mission instruments.

Instruments		Time scale	Requirements ($\theta x/\theta y$)	Unit
Solar UV-Vis-IR telescope (*)		1 sec	0.015	arcsec 3σ
		10 sec	0.015	arcsec 3σ
		1 hour	2	arcsec 0-p
		Mission life	20	arcsec 0-p
UV/EUV spectroscopic telescope		0.5 sec	0.3	arcsec 3σ
		5 sec	0.3	arcsec 3σ
		1 hour	2	arcsec 0-p
		Mission life	32	arcsec 0-p
X-ray telescope	Normal incidence (*)	1 sec	0.1	arcsec 3σ
		10 sec	0.1	arcsec 3σ
	Grazing incidence	1 sec	0.3	arcsec 3σ
		1 min	0.7	arcsec 3σ
		1 hour	8	arcsec 0-p
		Mission life	32	arcsec 0-p

Instruments		Time scale	Requirements (θz)	Unit
Solar UV-Vis-IR Telescope		1 hour	50	arcsec 0-p
UV/EUV spectroscopic telescope		1 hour	100	arcsec 0-p
X-ray telescope	Normal incidence	1 hour	50	arcsec 0-p
	Grazing incidence	1 hour	100	arcsec 0-p

(*) The pointing stabilities are to be achieved with the usage of an image stabilization system inside the telescopes.

It is important to identify critical items to achieve the pointing stability requirements by comparing on-orbit pointing performance of HINODE that achieved the highest pointing stability in Japanese space missions. We evaluate the pointing stability of HINODE in the frequency domain using telemetry data taken with the Ultra Fine Sun Sensor (UFSS) and the mechanical gyroscope (Inertia Reference Unit, IRU) that are components of the attitude and orbit control system (AOCS) on-board HINODE. They provide residual pointing errors with a temporal sampling of 0.5 sec, which provides the pointing stability in the frequency domain lower than 1 Hz. The correlation tracker (CT) on-board HINODE provides signals of pointing errors with a temporal sampling of 580Hz, which is used to evaluate high frequency disturbances in the frequency range between 0.1 Hz and 290 Hz. The on-orbit pointing stability evaluated with UFSS, IRU, and CT of HINODE is shown in Figure 5.7, as comparison with the requirements on the pointing stability for HINODE (top) and SOLAR-C (bottom). It is found that the AOCS on-board HINODE delivers better performance than the requirements in the frequency range lower than 0.1 Hz (upper limit of the AOCS control band). It is important to note that, without the image stabilization system, it is difficult to realize the good spatial resolution with SOT because the pointing stability of about 0.1 arcsec (0-p) at 0.1 Hz achieved with the AOCS is worse than the requirements of SOT. The image stabilization system has a crucial role in the reduction of the attitude jitter in the frequency range between 10^{-2} Hz and 10 Hz.

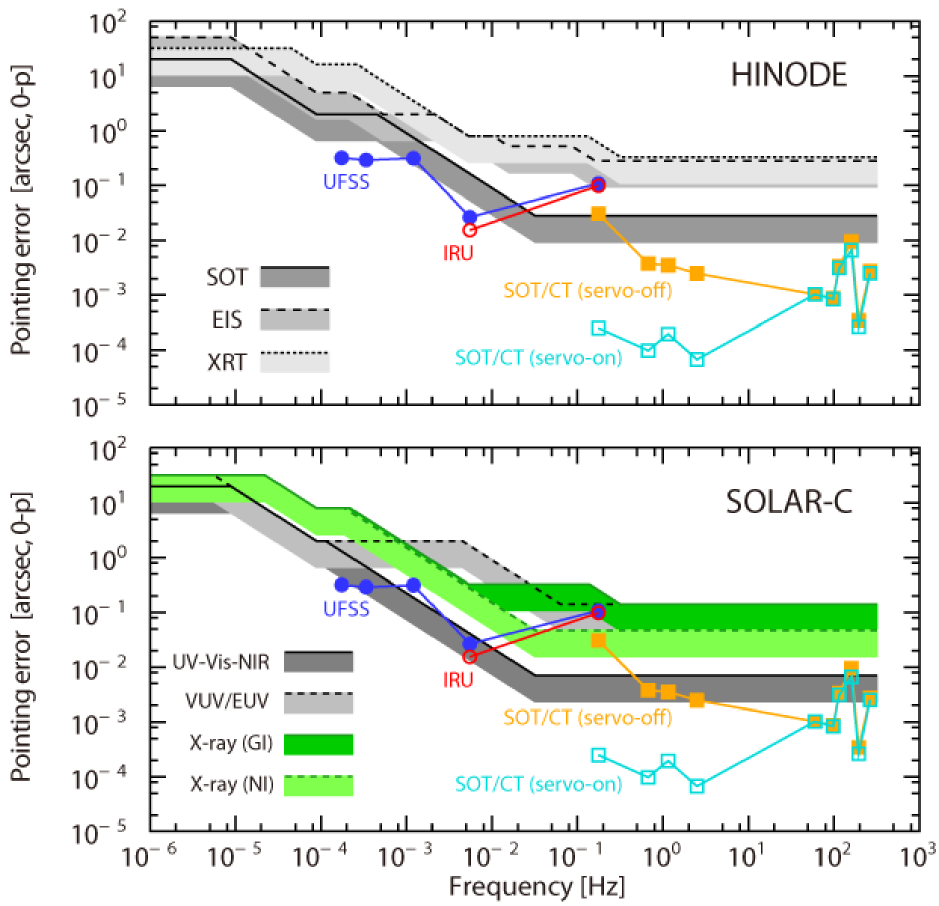

Figure 5.6. On-orbit performance of the pointing stability in HINODE in comparison with the requirements of the pointing stability for the mission instruments aboard HINODE (*top*) and SOLAR-C (*bottom*). The thick, dashed and dotted lines represent the requirements as a function of frequencies while the lower boundaries of the shaded belts indicate conditionally acceptable level, which is defined as one third of the requirements. The blue filled circles show the pointing stability evaluated with UFSS, the red open circles are that with IRU. The open cyan squares indicate the pointing stability evaluated with CT in the case of servo-on, and filled orange squares are that in the case of servo-off.

By comparing the on-orbit pointing performance of HINODE with the requirements for SOLAR-C, we have identified three critical items for further improvements necessary in the Plan B spacecraft:

(1) Orbital variation (10^{-3} – 10^{-5} Hz)

It is caused by misalignment between the attitude sensors and the telescopes due to thermal deformation of structures supporting them. In the case of SSO, temperature fluctuation is mainly induced by significant influence of infrared radiation from the earth. In SOLAR-C, the orbital variation is to be reduced significantly thanks to the lower temperature fluctuation at GEO.

(2) Degradation of the pointing stability at around 0.1 Hz

There is an unexpected degradation at around 0.1Hz in the on-orbit pointing performance of HINODE. The frequency of 0.1 Hz corresponds to the upper limit of controllable frequency of the AOCS. The stability is 0.1 arcsec (0-p), which is not enough to achieve the spatial resolution better than about 0.3 arcsec. It is necessary to clarify the cause and to improve the AOCS not to induce the degradation in SOLAR-C. If it is difficult to improve the pointing stability at around 0.1Hz only with the AOCS, the mission instruments have to be equipped with an image stabilization system inside them.

(3) High-frequency disturbances (>100 Hz)

The disturbances at the frequencies higher than 100 Hz have to be suppressed to achieve the resolution of 0.1 arcsec in SUVIT of SOLAR-C. They are induced by structural resonance between the telescope structures and disturbances of momentum wheels (MWs) and mechanical gyros. Because the image stabilization system aboard HINODE is not effective to such high-frequency (>20 Hz) disturbances, one possible approach is to improve the image stabilization system to have a broader response in the frequency as high as 100-200 Hz. The other approach is to suppress generation or transmission of the disturbances from MWs and the mechanical gyroscopes, which is technically possible if MWs are mounted on a vibration isolation bench.

5.4.2. Attitude control system

The attitude control system provides three-axis stabilization of the spacecraft to point to an observing target on the solar surface. We can basically use the same configuration as HINODE, which achieved the highest pointing stability in Japanese space missions, but some modification is necessary in order to improve the items required for further improvements of the pointing stability described in section 5.4.1. Major components in the attitude control system are listed below.

- Attitude and orbital control processor (AOCP)
  - The attitude computer is based on Hinode and other JAXA spacecrafts.
- Ultra Fine Sun Sensor (UFSS)
  - The sensor precisely measures the direction of the Sun with sub arc second accuracy.
  - The performance of UFSS on-board HINDOE is enough for the Solar-C requirements.

- Fine Sun Sensor (FSS)
  - The planned sensor has been used on Planet-C and so on.
- Star Tracker (STT)
  - The start tracker measures the roll around the direction of the Sun.
  - The performance of the star trackers used in other spacecrafts meets the Solar-C requirements.
- Tuned Dry Gyroscope (TDG)
  - The gyroscope measures the angle change of the spacecraft attitude as an inertia reference unit (IRU).
  - TDG has been used in many space missions in Japan. We have to investigate the possibility to reduce the disturbances caused by the mechanical gyroscope.
  - As an alternate option, fiber optic gyroscope (FOG) is considered for a disturbance-free gyroscope.
- Geomagnetic Aspect Sensor (GAS)
  - The sensor may be purchased from an aerospace company.
- Momentum wheels (MW)
  - Momentum wheels are used as actuators of the spacecraft attitude.
  - The baseline for momentum wheels is same as used in Hinode.
  - For suppressing transmission of the micro-vibration disturbances, vibration isolation bench may be required to mount momentum wheels.
- Magnetic torquer (MTQ)
  - The sensor may be purchased from an aerospace company (following the previous missions).

5.4.3. Flexibility on the role attitude

In the Hinode case, the spacecraft role is always fixed to align the spacecraft Y-axis, i.e., Y direction of CCD detectors, to the solar North-South direction. For the Solar-C Plan B mission, it would be useful to allow changing the spacecraft role attitude, depending on the nature of observing target. For example, when the slit of spectroscopic telescopes is placed along a coronal loop structure, the spectroscopic telescopes can record spectral lines as a function of spatial position along the loop structure with very limited number of slit scan positions (or in sit-and-stare mode). This can provide high cadence of observations, allowing us to track energy flows along magnetic fields.

This capability will be considered in the AOCS functional design. It would be not difficult in implementing this capability from viewpoint of AOCS. However, this capability would give complication to the command uplink and telemetry downlink operations. We may need more number of onboard antennas to cover any directions for the communication link with a ground station. Or, insufficient communication link level may be given depending on the roll angle.

5.5. Spacecraft thermal design to dump heat load from 1.5m telescope

In the thermal design of the spacecraft system, we basically follow the same concept as adapted in HINODE, which is summarized in the following:

- The OBU is made of low-thermal expansion and high-thermally conductive CFRP.
- The telescopes are thermally isolated from OBU and the spacecraft bus.
- The OBU is thermally isolated from the spacecraft bus.

However, as described in section 4.3.4, some part of the large heat load given to the primary mirror (M1) of the UV-Visible-IR telescope (SUVIT) needs to be transferred toward the spacecraft bus direction (-Z direction). With having the heat path toward the bus direction, the temperature of M1 can be kept well within the acceptable temperature range. Thus, a thermal interface is required between the SUVIT's primary mirror and the spacecraft. A preliminary thermal concept is to have heat pipes to transfer the heat to the radiators equipped at the bus side (Figure 5.8). The heat load at M1 is dumped to a cold plate located behind M1 with radiation. Heat pipes connect the cold plate to the radiators on the side of the bus or OBU structure. The heat load of about 100 – 200 W is required to transfer via heat pipes. A preliminary study shows that the size of the radiators necessary for 100-200W heat dump can be accommodated either on the side of the bus module or OBU structure.

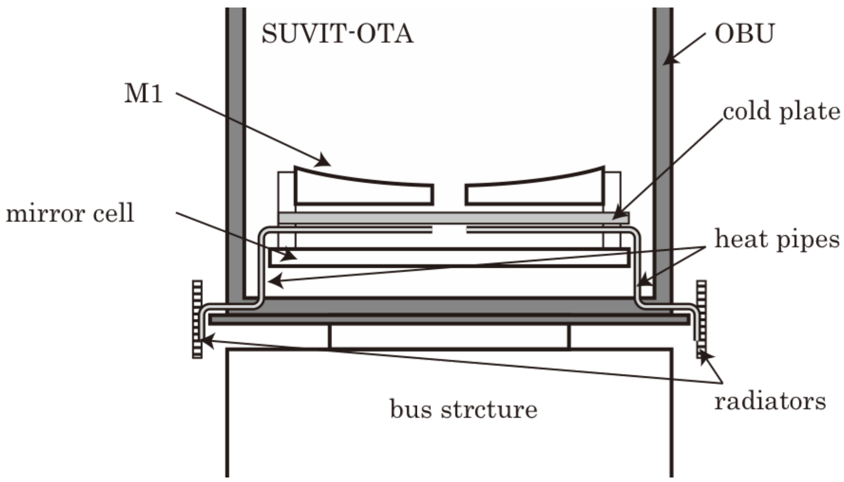

Figure 5.7. Thermal design concept to dump the heat load from M1 of the SUVIT-OTA.

5.6. Spacecraft power system

The spacecraft has solar array panels that generate the electric power. Considering the size of the Bus module and telescopes, 4 solar array panels would be a baseline. They are attached on the Bus; either two wings, each of which has two panels, as shown in Figure 5.1, or 4 panels (wings) at each face of the Bus module.

The 4 panels can generate the power up to ~3500W. The power budget will be evaluated in the design phase, but we will have no critical concerns on the power budget, from our former experience on Hinode (~1100W).

The proposed orbit provides a long continuous duration of non-eclipse condition. For eclipse periods and initial launch operation, the power system needs a power battery to provide the electrical power to the onboard components. The size of buttery will be determined after the initial evaluation of power budget in the design phase.

The power system provides an unregulated 50V power to all the components on board; 50-52 V in non-eclipse period and 30-49V in the eclipse period, which is same as used in Hinode.

5.7. Science operations

Since the spacecraft is viewed for a long duration from a ground station (USC), science daily operations may become more flexible than Hinode's operation. The following methodology may be added to the science planning scheme; an observer in the operation room checks images in real time, and make commands for adjusting the telescope pointing to the small area of interest, and then the operator uplinks the commands to the spacecraft during a contact (Figure 5.9). This kind of operations would be very powerful, because telescopes may have the field of view smaller than Hinode and the slit position for spectroscopic telescopes is very critical to capture the phenomena of interest.

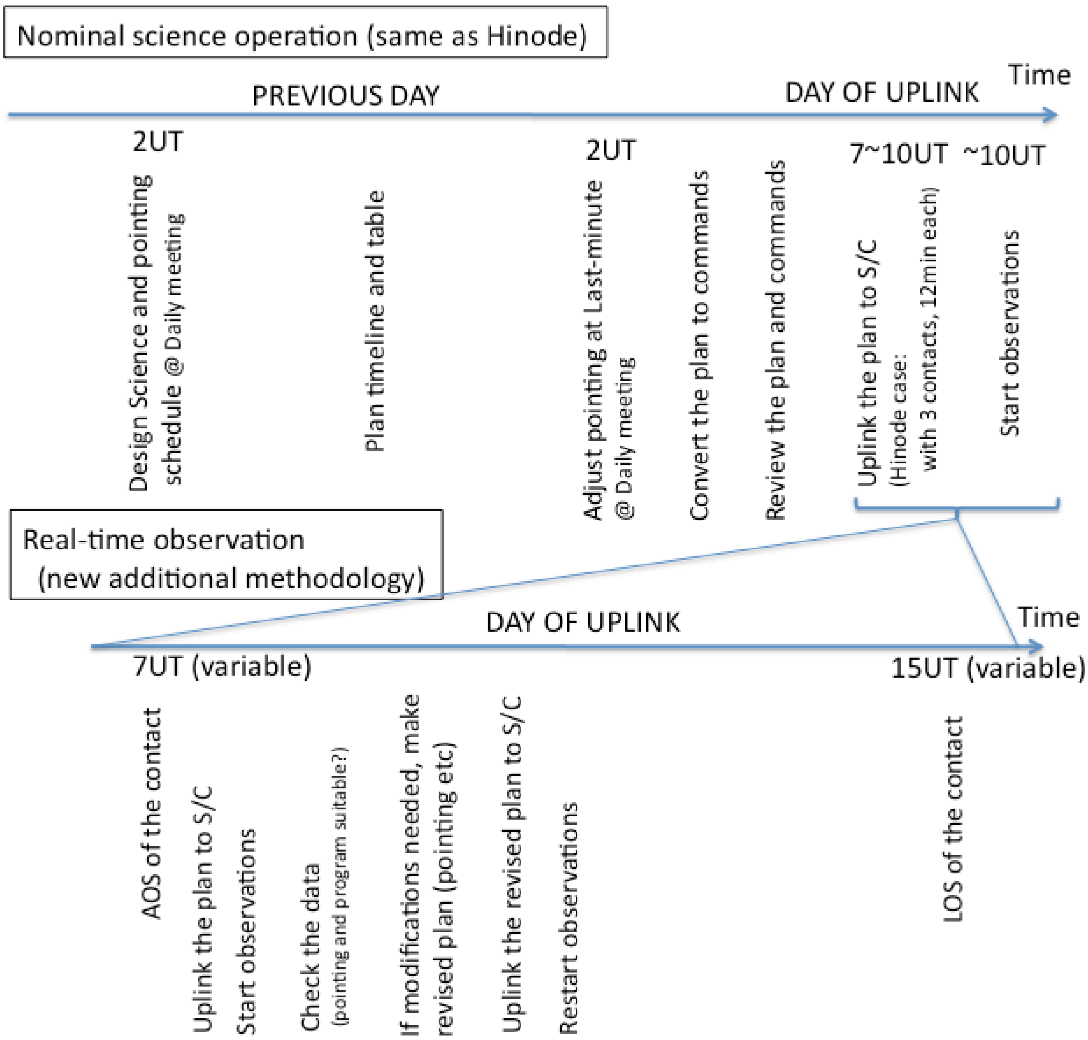

Figure 5.8. A new methodology of science operations that can be considered in the GEO case

Appendix 5-A. Data rate estimate

We here estimate data production rates from the mission instruments using their preliminary design including formats of their detectors and typical exposure duration in order to clarify how much telemetry rate is required to download the data from the spacecraft to the ground. We define two typical observing cases for each instrument; one is for continuous observations without interruption ("standard case"), which produces a lower data rate, and the other is for short-term burst observations ("burst case"), which produces a higher data rate. In the estimation, we assume a bit depth of their data products, and how much the data amount can be shrunk with lossless and lossy compression algorithms. Details are summarized in the following.

- Solar UV-Vis-IR telescope (SUVIT) / Spectrograph package
  - Standard case:
    - In this case, we can achieve high signal-to-noise ratio of about 10^4 with deep integration for measuring chromospheric magnetic fields.
    - Number of pixels of an image set:
      1024 (spatial) x 512 (wavelength) x 4 (Stokes) x 2 (orthogonal pol.)
      = 4 Mpixel
    - Bit depth:
      16bit/pixel (no comp.), 7bit/pix (lossless comp.), 3bit/pix (lossy comp.)
    - Temporal cadence:
      10 sec at each slit position

    → 6.4 Mbps (no comp.), 2.8 Mbps (lossless comp.), 1.2 Mbps (lossy comp.)

  - Burst case:
    - In this case, we can achieve standard signal-to-noise ratio of about 2×10^3 with 1 sec integration for rapid slit scanning.
    - Number of pixels of an image set:
      2048 (spatial) x 1024 (wavelength) x 4 (Stokes) x 2 (orthogonal pol.)
      = 8Mpixel
    - Bit depth:
      16bit/pixel (no comp.), 6bit/pix (lossless comp.), 2bit/pix (lossy comp.)
    - Temporal cadence:
      1 sec at each slit position

    → 128.0 Mbps (no comp.), 48.0 Mbps (lossless comp.), 16.0 Mbps (lossy comp.)

- Solar UV-Vis-IR telescope (SUVIT) / Imager package
  - Standard case:
    - In this case, we get minimum wavelength sampling for Dopplergrams with the narrow-band filtergraph with reduced spatial and temporal sampling.
    - Number of pixels of an image set:
      2048 x 2048 (spatial) x 5 (wavelength)
      = 20 Mpixel

- Bit depth:
  12bit/pixel (no comp.), 5bit/pix (lossless comp.), 2bit/pix (lossy comp.)
- Temporal cadence:
  30 sec for each wavelength scan

→ 8.0 Mbps (no comp.), 3.3 Mbps (lossless comp.), 1.3 Mbps (lossy comp.)

- Burst case:
  - In this case, we get full wavelength sampling of a spectrum line for imaging-spectroscopic observations with the narrow-band filtergraph with full spatial and temporal sampling.
  - Number of pixels of an image set:
    4096 x 4096 (spatial) x 10 (wavelength)
    = 160 Mpixel
  - Bit depth:
    12bit/pixel (no comp.), 5bit/pix (lossless comp.), 2bit/pix (lossy comp.)
  - Temporal cadence:
    10 sec for each wavelength scan

  → 192.0 Mbps (no comp.), 80.0 Mbps (lossless comp.), 32.0 Mbps (lossy comp.)

- UV/EUV high-throughput spectroscopic telescope
  - Standard case:
    - In this case, we get a reduced set of spectrum lines with deep integration.
    - Number of pixels of an image set:
      2048 (spatial) x 128 x 10 (wavelength)
      = 2.5 Mpixel
    - Bit depth:
      14bit/pixel (no comp.), 6bit/pix (lossless comp.), 3bit/pix (lossy comp.)
    - Temporal cadence:
      5 sec at each slit position

    → 7.0 Mbps (no comp.), 3.0 Mbps (lossless comp.), 1.5 Mbps (lossy comp.)

  - Burst case:
    - In this case, we get a full set of spectrum lines with shorter integration for rapid slit scanning.
    - Number of pixels of an image set:
      2048 (spatial) x 256 x 20 (wavelength)
      = 10 Mpixel
    - Bit depth:
      14bit/pixel (no comp.), 6bit/pix (lossless comp.), 3bit/pix (lossy comp.)
    - Temporal cadence:
      1 sec at each slit position

    → 140.0 Mbps (no comp.), 60.0 Mbps (lossless comp.), 30.0 Mbps (lossy comp.)

- X-ray imaging (spectroscopic) telescope
  - Assumptions:
    - Perform tagging for each photon-incident event
    - Tagging information
      - ✓ Pixel address (X, Y)
      - ✓ Photon energy
      - ✓ Incident time
    - No on-chip/on-board pixel summing. Perform on ground if necessary.
    - Data compression may be possible, which reduces data rate to half.

  - Standard case:
    - In this case, we get photon counting imaging spectroscopy in 128 x 128 pixels ROI.
    - Pixel address (X, Y):
      7 bits x 2 = 14 bits (for 0–127)
    - Photon energy:
      10 bits (0–1023 ch)
    - Exposure time:
      every 1 ms
    - Ratio of event pixels:
      2 % (i.e., 128^2 x 10% = 327.7 pixels contain events)

    → 6.9 Mbps (no comp.), 3.5 Mbps (comp.)

  - Burst case:
    - In this case, we get photon counting imaging spectroscopy in 512 x 512 pixels ROI.
    - Pixel address (X, Y):
      9 bits x 2 = 18 bits (for 0–511)
    - Photon energy:
      10 bits (0–1023 ch)
    - Exposure time:
      every 1 ms
    - Ratio of event pixels:
      10 % (i.e., 512^2 x 10% = 6553.6 pixels contain events)

    → 110.0 Mbps (no comp.), 55.0 Mbps (comp.)