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# PRELIMINARY FEASIBILITY STUDY OF THE SOLAR OBSERVATION PAYLOADS FOR STSAT-CLASS SATELLITES

**Yong-Jae Moon[1] †, Kyung-Seok Cho[1], Ho Jin[1], Jongchul Chae[2],**
**Sungho Lee[1,2], Kwang-Il Seon[1], Yeon-Han Kim[1], and Young-Deuk Park[1]**
[1]Korea Astronomy Observatory, Whaamdong, Yooseong, Daejeon 305-348, Korea
[2]Astronomy Program, School of Earth and Environmental Sciences, Seoul National University, Seoul 151-742, Korea
E-mail: yjmoon@kao.re.kr

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## ABSTRACT

In this paper, we present preliminary feasibility studies on three types of solar observation payloads for future Korean Science and Technology Satellite (STSAT) programs. The three candidates are (1) an UV imaging telescope, (2) an UV spectrograph, and (3) an X-ray spectrometer. In the case of UV imaging telescope, the most important constraint seems to be the control stability of a satellite in order to obtain a reasonably good spatial resolution. Considering that the current pointing stability estimated from the data of the Far ultraviolet Imaging Spectrograph (FIMS) onboard the Korean STSAT-1, is around 1 arc minutes/sec, we think that it is hard to obtain a spatial resolution sufficient for scientific research by such an UV Imaging Telescope. For solar imaging missions, we realize that an image stabilization system, which is composed of a small guide telescope with limb sensor and a servo controller of secondary mirror, is quite essential for a very good pointing stability of about 0.1 arcsec. An UV spectrograph covering the solar full disk seems to be a good choice in that there is no risk due to poor pointing stability as well as that it can provide us with valuable UV spectral irradiance data valuable for studying their effects on the Earth's atmosphere and satellites. The heritage of the FIMS can be a great advantage of developing the UV spectrograph. Its main disadvantage is that two major missions are in operation or scheduled. Our preliminary investigations show that an X-ray spectrometer for the full disk Sun seems to be the best choice among the three candidates. The reasons are : (1) high temporal and spectral X-ray data are very essential for studying the acceleration process of energetic particles associated with solar flares, (2) we have a good heritage of X-ray detectors including a rocket-borne X-ray detector, (3) in the case of developing countries such as India and Czech, solar X-ray spectrometers were selected as their early stage satellite missions due to their poor pointing stabilities, and (4) there is no planned major mission after currently operating Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) mission. Finally, we present a preliminary design of a solar X-ray spectrometer covering soft X-ray (2 keV) to gamma ray (10 MeV).

*Key words*: solar space mission, solar UV and X-ray observations, solar flare

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† corresponding author

# 1. INTRODUCTION

Korea has a relatively short history of space missions. Especially, for space science and astronomy, there have been only four micro satellite programs : a series of three KITSAT (Korea Institute of Technology; Wooribyul) and the first Korean Science and Technology Satellite (STSAT-1). At present, the STSAT-2 is under development and is scheduled to be launched in a few years by the first Korean made launch vehicle (KSLV-I). Due to such a short history and the lack of related technologies, there are a lot of constraints on the selection of a payload, as will be illustrated in the next sections.

In this paper, we are going to introduce three types of solar candidates for future Korean STSAT programs and discuss their feasibility. In fact, the solar observations in space have several advantages over other observing targets, especially in the case of very early stage space programs such as our STSAT programs; (1) since it is the brightest celestial body in the sky, we have relatively sufficient photons in nearly all wavelengths, which make it possible to make short exposure observations compensating for poor pointing stability, (2) since it has a quite large angular size (about 30 arc minutes), it is possible to observe large-scale structures in the solar atmosphere with such a small telescope with about 10 cm diameter, (3) we can expect joint observations between solar and in-situ measurements of space environment since solar activity is regarded to be a major driver of the disturbances in space environment. Our discussions on the three candidates are rather limited to the scientific requirements of solar astronomers such as data usefulness, and sufficient temporal and spatial resolution. In addition, we briefly discuss their current status and related heritages in terms of technologies. This paper is purposed for providing scientists and related engineers with basic information for selecting a proper solar space mission for future Korean satellites under our current status in science and technology.

The paper is organized as follows. We describe current constraints for the Korean ST satellites in Section 2 and discuss the feasibility of three solar candidates in terms of science and technology in Section 3. Finally, a brief summary and discussions are delivered in Section 4.

# 2. CONSTRAINTS FOR CURRENT KOREAN SCIENCE & TECHNOLOGY SATELLITES

In this section, we summarize major constraints for the Korean STSAT-2 under development and Lyman-$\alpha$ Imaging Solar Telescope (Jang 2003). The followings are the main parameters of the STSAT-2 from the Preliminary Design Review (PDR):

(1) Mass: 15 kg
(2) Volume: 130 $\Phi \times$ 430 mm
(3) Pointing accuracy: 0.15 degree
(4) Control stability: 0.002 degree/sec
(5) Average power: 20 W
(6) Pixel resolution for 1K CCD: 2.64 arc seconds
(7) Exposure time: 0.1 -1 second
(8) Field of view: 45 arc minutes
(9) Mass memory: 2 Gbits
(10) Telemetry: 10 Mbps
(11) Data transfer: 16 frames/orbit = 32 Mbyte/orbit
(12) Orbit: 1500 km × 300 km elliptical orbit
(13) Orbital Period: $\sim$ 100 minutes

These parameters will be used as basic constraints for our discussions. We hope that these parameters will be greatly improved in the near future. In another aspect, we also discuss what kind of parameters are essential and should be improved for the three candidate missions.

## 3. SOLAR CANDIDATES

In this section, we discuss the feasibility of three types of solar candidates for Korean STSAT missions. For our discussion, we consider similar space missions that are currently developed or were already considered.

### 3.1 UV Imaging Telescope

Recently, UV imaging telescopes have played very important role in studying solar activity such as solar flares and coronal mass ejections (CMEs). Since the images taken by Solar Heliospheric & Observatory / Extreme ultraviolet Imaging Telescope (SOHO/EIT, Delaboudiniere et al. 1995) have been very regularly taken (approximately every 12 minutes) for the solar full disk with intermediate spatial resolution (around 5.3 arc seconds) since 1996, they have been widely used for identifying large-scale structures of 0.1-1 million degree coronal plasma associated with solar flares and CMEs (e.g., Neupert et al. 2001, Moon et al. 2003) as well as for studying other phenomena associated with solar activity such as EIT waves (e.g., Thompson et al. 1999, Moon et al. 2004a) and coronal dimming (e.g., Wang et al. 2002, Moon et al. 2004b). Since Transition Region and Coronal Explorer (TRACE, Handy et al. 1999) images have been taken with high temporal (less than one minute) and spatial (about 1 arc seconds) resolutions for local area of the Sun, they have been usually used for studying physical characteristics of small-scale structures in the transition region and corona (e.g., Chae et al. 1999, Chae et al. 2002) as well as their relationship with other structures such as cancelling magnetic features (e.g., Chae 2003, Moon et al. 2004a). In this section, we mainly discuss the feasibility of the UV imaging telescope in terms of their spatial and temporal resolution for science.

In the case of UV imaging telescopes, one of the key points to determine successful operations is whether spatial and temporal resolutions are sufficient for scientific studies. In the case of currently operating solar space missions, their spatial resolutions are around five arc seconds (e.g., SOHO/EIT) for full-disk images or around 1 arc seconds (e.g.,TRACE) for local images. Since pointing parameters (accuracy and stability) of Korean STSAT programs are not so good, their payload should be an UV imaging telescope for the solar full disk rather than for its local area. According to the PDR of the STSAT-2, the pointing stability is reported to be 0.002 degree/sec (about 7 arc seconds/sec). But we recently realized that this value corresponds to the drift rate of a gyro, rather than the pointing stability itself (Lee 2004). Usually, the pointing stability is defined as the maximum rate of change of angular orientation (Larson & Wertz 1992). The first satellite of the STSAT programs may provide a rough estimation on the practical pointing stability of the future STSAT satellites. We thus examined the pointing stability of STSAT-1, although its correct estimation is impossible with the currently available data. We selected an orbit during which an uniform rotation rate was planned, and estimated angular deviations from the smooth rotation. Figure 1 shows the angular deviations estimated during the orbit. The estimated deviation from the planned attitude is around 1 arc minutes/sec in maximum value, and around 0.5 arc minutes/sec in the root-mean square value. Thus, the real pointing stability, at least in practical sense in that a payload has no better attitude information, could be thought to be about this value, and the value is about ten times worse than the value in the PDR of STSAT-2.

To minimize such a shortcoming, a shorter exposure time is desirable. Thus, the determination

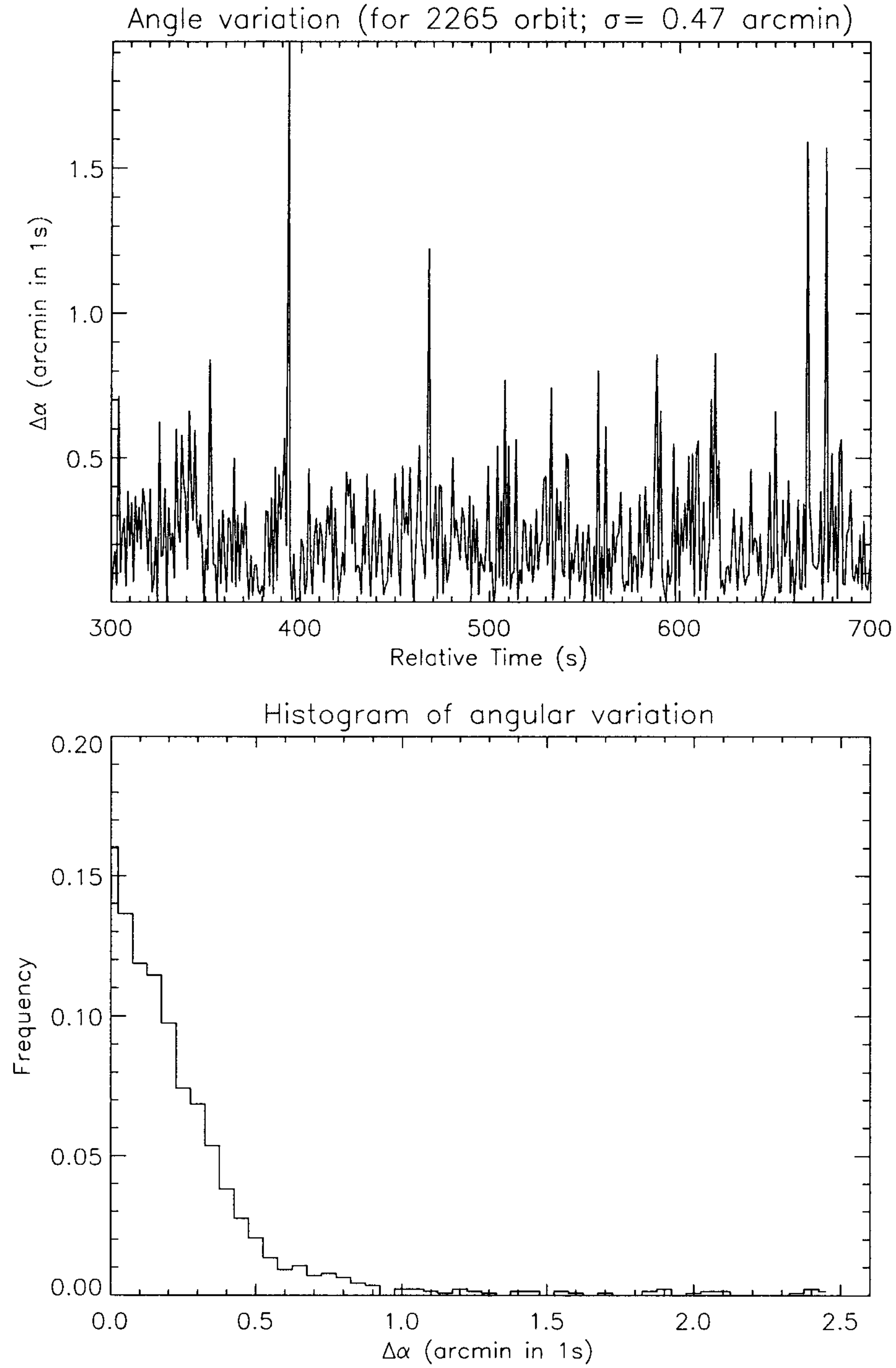

Figure 1. Temporal variation (top) of pointing stability of STSAT-1/FIMS and its histogram (bottom).

of a proper exposure time is quite important since we also need enough photons and signal to noise ratio (hereafter, S/N) to get high quality images. The signal (S) per CCD pixel per second in unit of the number of electron is given by

$$\mathrm{S} = \mathrm{A_{ap}\Omega_{pixel}I_{source}T_{filter}R_{mirror}Q_{ccd}/E_{ph}}, \tag{1}$$

where $A_{ap}$ is an area of aperture, $\Omega_{\mathrm{pixel}}$ is the solid angle of a pixel in a CCD, $\mathrm{I_{source}}$ is the integrated line intensity of a target source, $\mathrm{T_{filter}}$ is the filter transmission, $\mathrm{R_{mirror}}$ is the mirror reflectivity, $\mathrm{Q_{ccd}}$ is the quantum efficiency of the CCD, and $\mathrm{E_{ph}}$ is the photon energy at a given frequency. According to Mclean (1997), the signal to noise ratio (S/N) in the case of no background can be approximated like

$$\mathrm{S/N} = \frac{\mathrm{S \times T_{exp}}}{\sqrt{(\mathrm{S \times T_{exp} + N_{dark} \times (T_{exp} + T_{read}) + N_{read}^2})}}, \tag{2}$$

where $\mathrm{T_{exp}}$ is the exposure time, $\mathrm{N_{dark}}$ is the dark noise, $\mathrm{T_{read}}$ is the readout time, and $\mathrm{N_{read}}$ is the readout noise. In this study, the Lyman-$\alpha$ spectral line is selected as an example since it is the strongest one in the UV spectral region. From the PDR of STSAT-2 and web resources on an UV CCD(e.g., E2V 47-10), we take the following parameters : $\mathrm{A_{ap}} = \pi(7.64)^2/4\mathrm{cm}^2$, $\Omega_{\mathrm{pixel}} = (2.64/206265)^2\mathrm{sr}$, $\mathrm{I_{source}/E_{ph}} = 2 \times 10^{15}$ photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$ (Prinz 1974), $\mathrm{T_{filter}} = 0.08^3$ for three filters, $\mathrm{R_{mirror}} = 0.7^2$ for two mirrors, $\mathrm{Q_{ccd}} = 0.2$, $\mathrm{N_{dark}} = 42$ electrons/s, $\mathrm{T_{read}} = 1$ sec, and $\mathrm{N_{read}} = 4$ electrons. According to Prinz (1974), the number of solar Lyman-$\alpha$ photons ranges from 1 to 10 $\times 10^{15}$ $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$(for details, see Fig. 5 of Prinz 1974). Thus the adopted source intensity is near the lower limit of expected intensity. Using the equations (1) and (2), we found that the approximate exposure time for S/N=10 is 0.2 second and the signal is 140 electrons.

If we assume that the pointing stability is linear with exposure time (optimistic assumption), the pointing stability is about 12 arc seconds when the exposure time is 0.2 second. This value is five times of the pixel resolution (2.64 arc seconds). Considering the fact that the spatial resolutions of current missions (e.g., SOHO/EIT and TRACE missions) range from 1 arc seconds to about 5 arc seconds, we think that 12 arc seconds is too large to do scientific studies. This fact implies that the pointing stability is a very critical constraint for UV imaging telescopes, at least in the early stage of space missions with poor pointing parameters. Even though the improvement of the pointing stability is the most desirable, its feasibility is not positive at present. Alternative way is to reduce the exposure time. If we use only two filters with $T_{filter} = 0.08^2$, then the exposure time would be in the range of 0.01 and 0.1 second. In this case, the effect of photons at other wavelengths are unavoidable. According to the PDR, when the three filters are changed to the two filters, the contamination from other wavelengths would increase from 1.89 to 10.63 %. Note that this estimation takes into account only the transmissions of the filters. If we consider the effect of the reflectivity of mirrors and the CCD quantum efficiency as a function of wavelength, the contaminations may be more serious. If we select this choice, further detailed examinations on this effect are needed. As another choice, we may adopt a lower S/N ratio with shorter exposures by just focusing on bright structures. However, it should be noted that we can not sure that a shorter exposure guarantees a better resolution, since we have no information on the temporal characteristics of pointing stability at the level of exposure times shorter than 1 second (i.e., high frequency component of jittering).

To select another wavelength can be a choice. In this case, it should be a wavelength at which it is possible to make short exposure observations to compensate for the poor pointing stability. Considering that Lyman-$\alpha$ is the strongest spectral line in far ultraviolet (FUV) and extreme ultraviolet (EUV) regimes, we have to consider UV continuum observations at wavelength longer than 2000

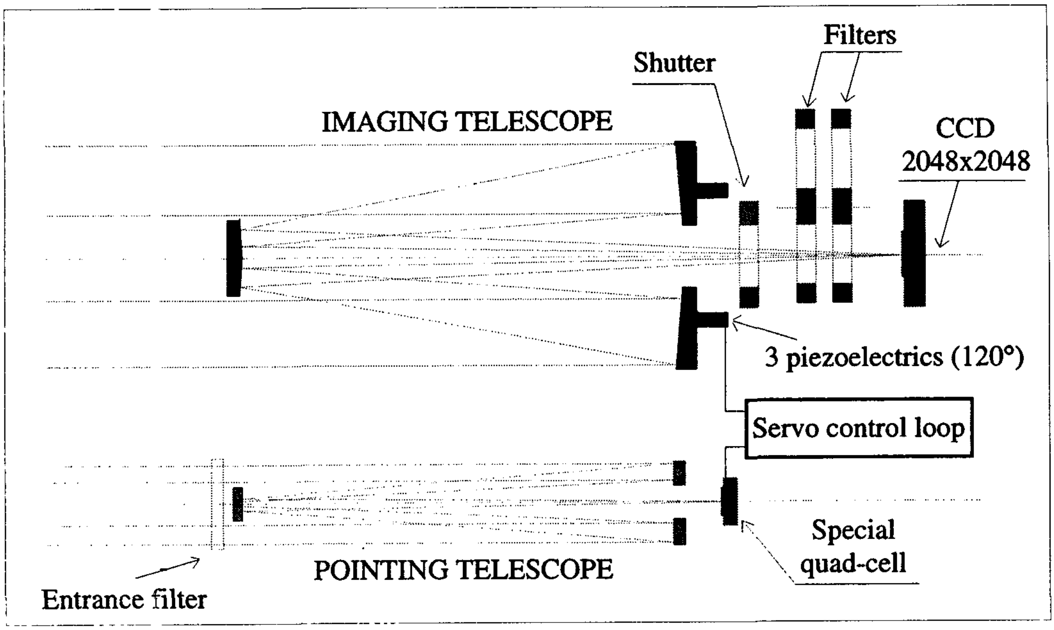

Figure 2. Optical Design of PICARD/SODISM (Dame et al. 2001).

Å or optical wavelengths to get enough photons. However, it is hard to find some scientific interests in this spectral regimes since the size of a telescope is not so large (less than 10 cm). In any cases, more detailed investigations which include the efficiency of optical elements and detector should be made in advance. If the weight and space of the payload are allowed, multi-band UV imaging telescopes like EIT and TRACE will be quite desirable for studying coronal temperature and density diagnostics (Chae et al. 2002).

Another key point is the temporal cadence of observation, which is mainly determined by the capabilities of mass memory and telemetry of a satellite. The estimated maximum number of frames from PDR is 16 frames per orbit (32 Mbyte/orbit), about 500 Mbyte per day. Since the orbital period is about 100 minutes and its duty cycle is around 50 %, the approximate time cadence of observation is around 3 minutes. This time cadence is mainly controlled by mass memory (2 Gbits = 250 Mbyte), image down-link rate (10 Mbps), and telemetry duration (900 sec). Total data memory (500 Mbyte) in a day is about two times of mass memory. This value seems to be controlled by twice-per-day data dumping from the mass memory to a ground station. In fact, the 3 minutes time cadence is four times better than that (typically 12 minutes) of SOHO/EIT and much worse than that of TRACE. But we still think that about 1 minute or even shorter time cadence is much desirable to study fine temporal variation of coronal plasma associated with solar flares and/or coronal mass ejections. We feel that further examinations are also needed to improve the temporal cadence of observations.

Figure 2 shows the optical design of a major instrument SOlar Diameter Imager and Surface Mapper (SODISM) for the PICARD micro-satellite program (Dame et al. 2001) which is scheduled to be launched in 2005. The SODISM will monitor solar EUV radiation including Lyman-$\alpha$ with four filters with a 2K CCD. One interesting point is that, while the pointing stability of its platform

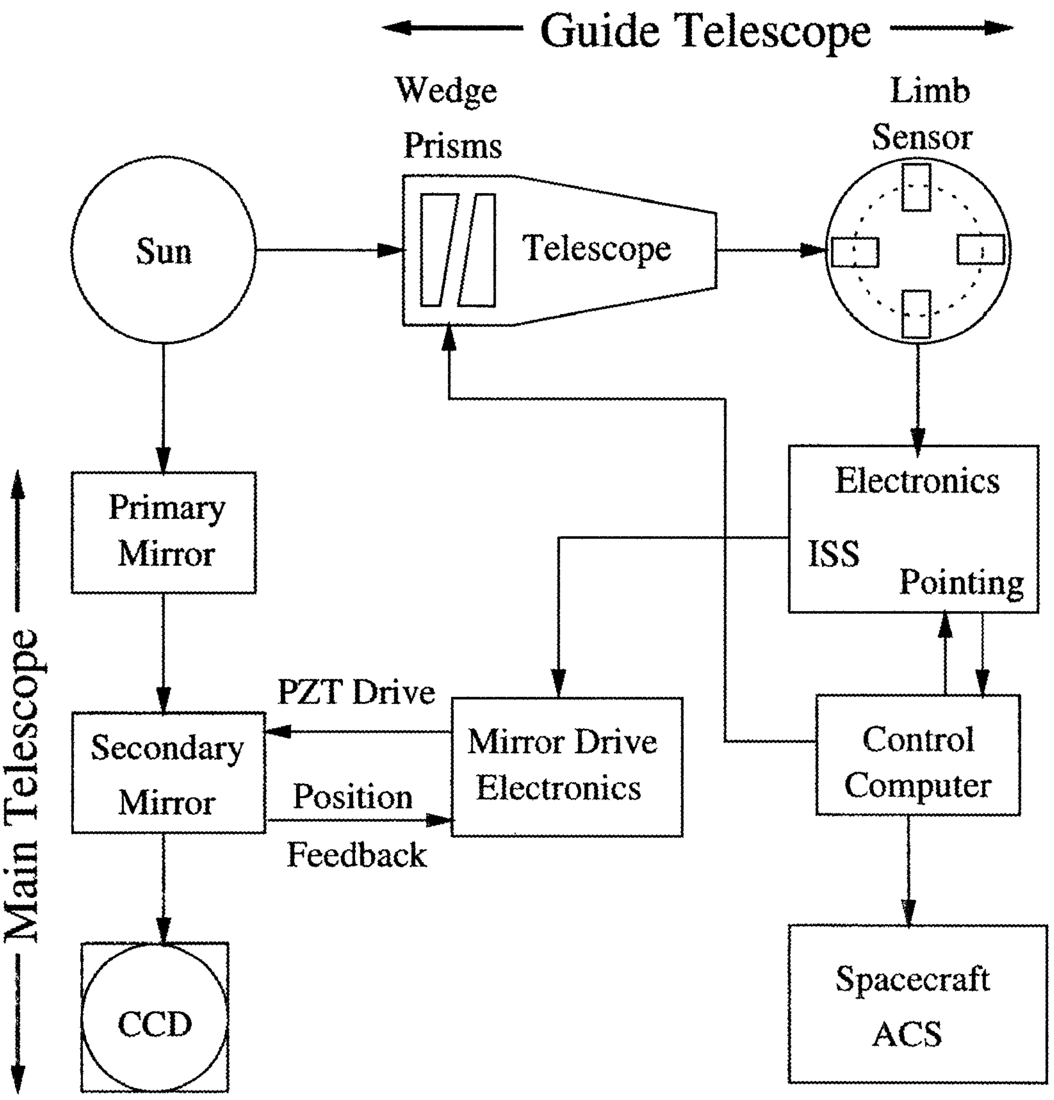

Figure 3. Guiding system of the TRACE (Handy et al. 1999).

is 0.01 degree, the pointing stability of SODISM is 0.1 arc seconds. For fine pointing needs, the primary mirror is mounted on a triad of piezoelectrics at 120 degree, which allows to limit the blur during the nominal 1 second exposure to 0.1 arc seconds. Figure 3 shows a schematic diagram of TRACE pointing system (Handy et al. 1999). In a cooperative mode with the spacecraft attitude control system (ACS), the guide telescope (GT) directs pointing maneuvers to desired solar targets. The image stabilization system (ISS) provides us with jitter removal to $\leq$ 0.1 arc seconds rms based on error signals from the GT (for more details, refer to Section 2.5 of Handy et al. 1999). As shown in Figures 2 and 3, such excellent pointing stability of about 0.1 arc seconds can be achieved by the servo controls based on the data (e.g., limb sensor data) from small guide telescopes. These facts imply that the image stabilization system using a guide telescope is quite essential for imaging the Sun with a very fine pointing stability. In other words, we can not expect such a fine pointing stability around 0.1 arc seconds from the direct control of a platform, especially in the case of micro satellites such as STSAT. If we have such an image stabilization system, the selection an imaging telescope becomes very reasonable. In this case, the selection of a 2K CCD may be a good choice for better spatial resolutions like PICARD/SODISM. However, it should be noted that higher spatial resolutions can be only made with poorer time cadence as far as telemetry is limited.

### 3.2 UV Spectrograph

Han et al. (2002) proposed an EUV spectrograph which can measure the spectral irradiance emitting from solar full-disk. The main characteristics of the solar UV spectrograph suggested by Han et al. (2002) are as follows: (1) spectral range: 300 – 1300 Å, (2) spectral resolution: 4 Å, (3) field of view: 3deg ×6 deg, (4) image detector: anode array with MCP, (5) filtered photodiode: 700 – 920 Å, (6) total mass: 13.5 kg, (7) total power: 27 W. These parameters well satisfy the constraints of STSAT programs. This spectrograph is quite similar to an EUV Grating Spectrograph (EGS) in the SEE (Solar EUV Experiment) instrument onboard Thermospheric Ionospheric Mesosphere Energetics and Dynamics (TIMED) satellite (http://lasp.colorado.edu/see/). The EGS is a Rowland-circle grating spectrograph that makes solar extreme ultraviolet (EUV) spectral irradiance measurements and covers the spectral range from 25 to 200 nm with 0.4 nm spectral resolution. The EGS protoflight version was used for a solar irradiance measurement in May 1997 on a sounding rocket. Its main scientific purpose is to monitor solar EUV spectral irradiance to study its effect on the Earth's high atmosphere. For example, the solar EUV spectral data such as E10.7 index can be used as a proxy for the variation of ionospheric F2 layer which is usually used for HF radio communication as well as for predicting satellite drags (Tobiska 2002). Thus its scientific field is closer to the Earth atmosphere than to solar astronomy. But we feel that it can provide us with very valuable data for the Sun-Earth connection studies. In addition, it has a couple of advantages like: (1) there is no risk due to poor pointing stability, and (2) the heritage of FIMS can be greatly helpful for developing this instrument, especially for a micro-channel plate (MCP) detector. Main disadvantage of the UV spectrograph is that there are two major missions that are in operation (SOLSTICE II: 1150-3200 Å, 2003–2007) or scheduled (Solar Dynamic Observatory (SDO)/Extreme Ultraviolet Variability Experiment (EVE): 50-1050 Å, 2007–). Since Han et al. (2002) described in detail the feasibility of this instrument, we do not describe more details here.

### 3.3 X-ray Spectrometer

It is well known that solar hard X-ray emissions result from non-thermal bremsstrahlung of energetic particles from solar flares. It is usually assumed that the initiation of strong hard X-ray emission indicates the starting of magnetic reconnection associated with flares. Thus the hard X-ray study in solar physics is thought to be quite essential in that it can provide us with very fundamental information on the flare process. While the full-disk monitoring of solar soft X-ray flux has been nearly continuously made by Geostationary Operational Environment Satellites (GOES) satellites since 1975, hard X-ray monitoring has been intermittently done.

Recently, high cadence flare observations became very important in that they can provide us with the information on high temporal fine structures. Regarding this, the Big Bear Solar Observatory (BBSO) group reported several interesting results from high cadence H-$\alpha$ and hard X-ray data (e.g., Wang et al. 2000, Qiu et al. 2002). Especially, Wang et al. (2000) identified the hard X-ray source with sub-second temporal characteristics, which may be called elementary flare bursts. To study such elementary bursts, a hard X-ray spectrometer with a high time resolution is quite essential. On the other hand, we have started a five year project with two items : (1) to develop two systems of solar radio burst locator (SRBL) using multi-band (1-18 GHz) microwave spectra and (2) to take part in the construction of 1.6 m new solar telescope (NST; Goode et al. 2003) with New Jersey Institute of Technology (NJIT). Through this project, we expect that SRBL and NST can provide us with microwave spectral and H-$\alpha$ imaging data with very high temporal resolutions. Combining these data with the data from an X-ray spectrometer with a fine temporal resolution, we can get very valuable data sets in order to study multi-wavelength high cadence flare characteristics using hard X-ray, microwave, and H-$\alpha$ data.

The Hard X-ray Burst Spectrometer (HXRBS) on the Solar Maximum Mission is the initial major mission using a hard X-ray spectrometer and produced valuable data to study important flare physics (Orwig et al. 1980). It used 15 channels covering the energy range from 20 to 260 keV with a time resolution of 0.1 second. Its total mass is 44.1 kg including the detector mass of 15.9 kg and its power is 7 W. Its detector is composed of a disk-shaped CsI (Na) central detector, CsI (Na) active collimator element and Photo Multiplier (PM) tubes. Recently, there was a joint program to make a Hard X-ray Spectrometer (HXRS) by the Astronomical Institute of the Academy of Science of the Czech Republic and the Space Environment Center (SEC) of the National Oceanic and Atmospheric Administration (NOAA)(Farnik et al. 2001). The X-ray spectrometer was designed to measure hard X-ray emission of the Sun in eight energy band covering 13-220 keV with high time resolution up to 200 ms. It has two scintillation detectors (NaI crystal + Hamamatsu PM tube) with in-flight radioactive calibration source ($Am^{241}$). Since it was the payload in a Low Earth Orbit (LEO) satellite, its real observation time is about one third of the total orbiting time; the night time is around 30 % and its passage time around South Atlantic Anomaly (SAA) is about 35 %. It is also noted that this kind of observing gab is disadvantageous. The Space Solar Telescope (SST; Ai et al. 2000) is planned by China and Germany. As a part of solar observing packages, there is a small hard X-ray detector with the following details: NaI Detector with 76 mm × 20 mm size, energy range of 15-450 keV (32 channels), time resolution of about 1 sec, power of 5 W, weight of 6 kg, data telemetry of 5 MByte/day, and 709 km sun synchronous polar orbit. As shown above, several payload parameters such as mass, power, and data telemetry are comparable to those of Korean STSAT-2.

Thanks to recent high technologies associated with solid detectors, we may consider an X-ray spectrometer having both . high time resolution and a high spectral resolution going down to as low as 2 keV (Dennis 2004). In fact, there are several room-temperature solid-state detectors that can give good sensitivity down to such low energies with sub-keV energy resolution. For example, silicon P-Intrinsic-N (Si PIN) detectors can go from about 2 to 15 – 20 keV. They allow the various atomic line complexes to be detected above the thermal free-free and free-bound continuum emission. Thus they can provide us with the information not only on the temperature and emission measure but also on the iron, calcium, and possibly other abundances. If this is combined with cadmium zinc telluride (CZT) detectors for the slightly higher energies, then we can cover the very interesting energy range up to 100 keV or higher where the thermal and nonthermal emissions overlap. Actually, the "Solar X-ray Spectrometer (SOXS)" mission onboard the GSAT-2 Indian spacecraft also adopted a PIN detector that is making interesting observations of solar flares in this energy range (Jain et al. 2004). Important details of the SOXS Low Energy Detector (SLED) are as follows (Jain et al. 2001, Jain et al. 2004): (1) Si PIN detector for the low energy X-rays (4-25 keV) with the energy resolution of 0.5 keV at 5.9 keV and CZT detector for the soft to medium hard X-rays (4-60 keV) with the energy resolution of 1.2 keV at 5.9 keV, (2) 18 kg mass (including the sun pointing mechanism), (3) 20 Watt power, (4) 5 Mbyte onboard memory, and (5) 8 kbs telemetry. These parameters well satisfy the constraints of the constraints of our STSAT programs if the sun pointing part is excluded.

Table 1. Preliminary evaluation of three candidates in several different aspects.

| | UV Imaging | UV Spectrograph | Hard X-ray Spectrometer |
|---|---|---|---|
| Science | CMEs and Flares | Sun-Earth connection | Flare physics |
| Heritage in Korea | LIST | FIMS | Rocket-borne |
| Public and outreach | Good | Middle | Middle |
| Pointing stability risk | Serious | Little | Little |
| Spatial Resolution | Poor | None | None |
| Temporal Res. | Middle | Good | Good |
| Scientific Usage | Middle | Good | Good |

Especially, the detectors have very good detection efficiency and superior energy resolution (10 % at 6 keV and about 3 % at 60 keV) compared to scintillation and proportional counters. Their major scientific objectives are to study (1) thermal and non-thermal contributions to a solar flare X-ray flux, (2) soft X-ray line emission, and (3) microflares. More details on scientific interest were well summarized by Jain et al. (2004).

Based on the above facts and suggestions by Hurford & Lin (2004), we propose an X-ray spectrometer whose block diagram is given in Figure 4. Its detector system consists of three kind of detectors: a silicon pin diode for low energies (2-20 keV); CZT for hard-x-ray energies (5-100 keV) and PM tube with scintillator for 50 keV to 10 MeV. CZT and silicon detectors provide excellent spectral resolution (0.6 and $\sim$ 3 keV respectively) and are very light. These detectors have 1 and 10 mil (1 mil = 25 $\mu$m) Be window to cut the background noise. A single CZT module is divided into a number (say 16) of small segments (typically 10 × 10 × 3 mm thick) to minimize capacitance for achieving the energy resolution. This division also has the advantage of minimizing dead time and pileup effects. The PM tube is of an anti-vibration type, and is magnetically shielded by micro-metal with NaI (TI) scintillation crystal window. Since the scintillator does not need to go to low energies, it can be located behind a passive shield to avoid livetime and pileup problems. These three detectors have different energy ranges and resolutions so that their interdependence measurement can give us a wide range of solar-X ray spectral information. We may use a small radioactive source like $Cd^{109}$ that emits lines at 22.3 and 25 keV, far from any line expected to occur in flare or in detector's dynamic range by any varying background. The front-end electronics has an aim to carry out the tasks of pulse shaping, pulse amplification, peak detection, and digital conversion of the input pulse train from our detector package. Such a combination of 3 detectors should be feasible within a 15 kg mass budget. There is also a lot of flexibility since the size of the scintillator can be chosen to use whatever mass budget is available. According to our preliminary estimate, the payload space is not too much required and the detector system also needs a reliable electronics to obtain solar X-ray data. Thus we think that the feasibility of related technologies is quite high since we have enough experience of X-ray detectors including a rocket-borne X-ray instrument (Nam & Choi 1998) as well as some experience to make space qualified electronics (Nam et al. 2002).

## 4. SUMMARY AND DISCUSSION

In this paper, we have examined the feasibility of the three types of solar observation palyoloads for future STSAT-class satellites from the viewpoints of science and technology. Our major conclusions for each candidate can be summarized as follows.

1. Considering that the Korean STSAT program does not have a good pointing stability, we think

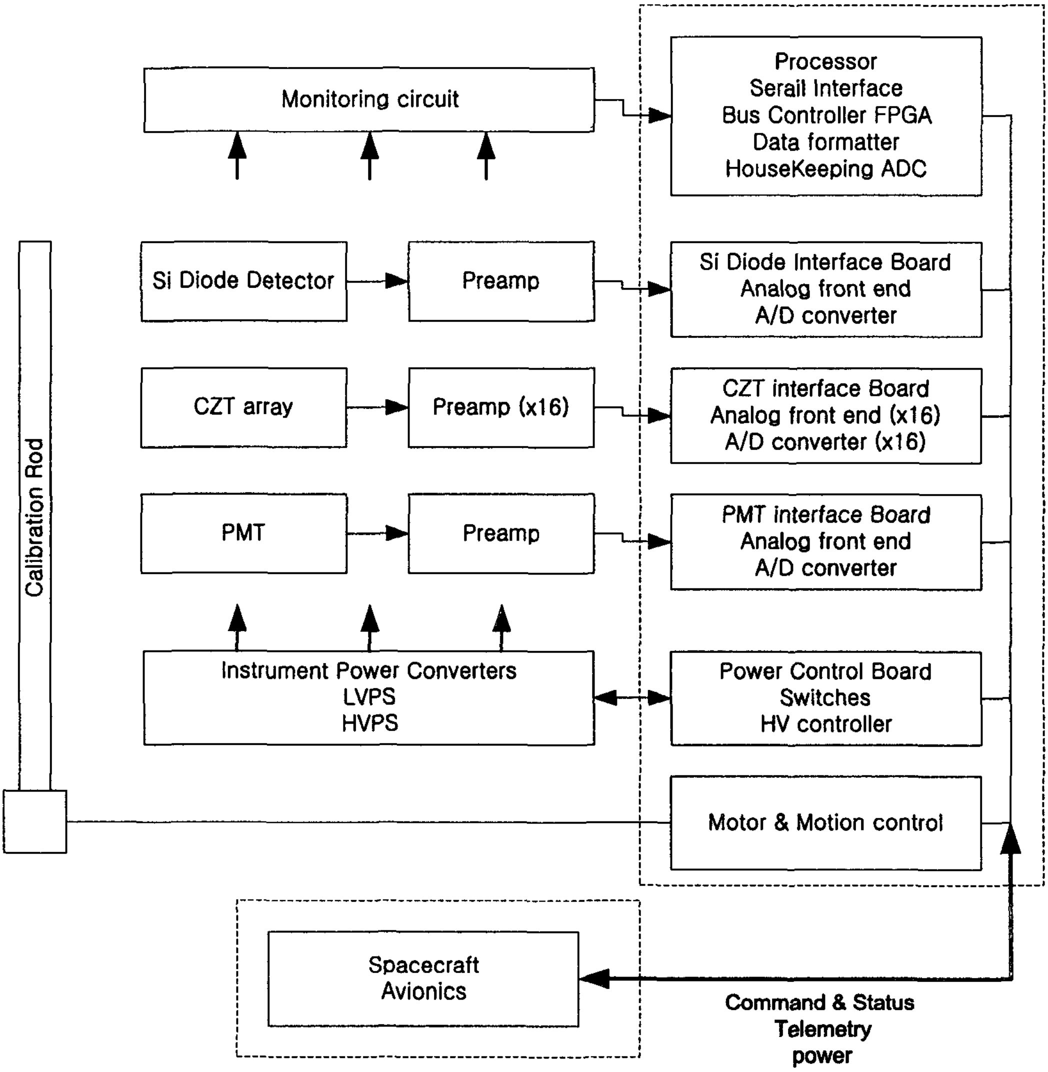

Figure 4. Block Diagram of the proposed X-ray spectrometer.

that the most important constraint for an UV imaging telescope is its control stability (jittering and drift per unit time) in order to obtain a reasonable spatial resolution. We realized that the pointing stability (around 1 arc minutes/sec) estimated from FIMS data is about 10 times worse than that (0.12 arc minutes/sec) from the PDR of Korean STSAT-2. At this point, we note that solar imaging missions (e.g., TRACE and PICARD/SODISM) with high spatial resolutions have their own image stabilization systems in the payloads to attain a very excellent pointing stability of about 0.1 arc seconds. These facts imply that it is quite essential to develop technologies associated with such image stabilization systems for UV imaging missions as well as other wavelength imaging missions.

2. An UV spectrograph for covering the solar full disk seems to be a good choice since (1) there is no risk due to the poor pointing stability, (2) it can provide us with valuable UV spectral irradiance data for studying the effect of solar UV radiation on the Earth's atmosphere and satellites, (3) we have a good heritage of the FIMS for the FUV observation. Main disadvantage of the UV spectrograph is that two major missions (SOLSTICE and SDO/SIE) are in operation or scheduled.

3. An X-ray spectrometer for the solar full disk can be also a good choice since (1) high temporal and spectral X-ray data are very essential for studying the acceleration process of energetic particles associated with solar flares, (2) we have a good heritage of rocket-borne X-ray detector (Nam & Choi 1998), and (3) there is no major mission since currently operating RHESSI mission (Lin et al. 2002).

Table 1 shows our preliminary evaluation of the three candidates. In fact, it is not easy to evaluate their feasibility quantitatively. We also admit that this quantitative estimation can depend on a person. In terms of science and heritage, three candidate have their own advantages and disadvantages. As for the public and outreach, the UV imaging mission may have the highest score if good quality of images are obtained from the mission. Many people may want to see high quality of space-based images that are not available from ground-based observations. However, it is not likely to get such images under the current pointing stability of Korean STSAT space program, as already discussed in the previous section. Thus we think that the UV spectrograph or the hard X-ray spectrometer can be a good choice. According to our preliminary judgement, the hard X-ray spectrometer seems to be the best choice among three candidates under consideration. Based on these facts, we proposed an solar X-ray spectrometer which is composed of three detectors (Si PIN, CZT, and PM tube with scintillator) covering soft X-ray to gamma ray, as described in Figure 4. In addition to three advantages described in the previous paragraph, we have two independent supports on this instrument. The one is that currently developing countries such as Czech Republic (Farnik et al. 2001) and India (Jain et al. 2004) have selected solar hard X-ray detectors as the payloads of their early stage space missions. The other is that two solar X-ray instrument groups (Brian Dennis from Goddard Space Flight Center in NASA and Gordon Hurford and Bob Lin from Space Science Lab. of UC Berkeley), which include key scientist and engineers of currently operating RHESSI mission, are willing to help us to prepare for an X-ray spectrometer.

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