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# The L5 mission for space weather forecasting

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**Abstract**

We have studied a number of interplanetary space mission scenarios for space weather research and operational forecasting experiments and concluded that a spacecraft should be deployed at the L5 point of the Sun–Earth system to enable remote sensing of the Sun and interplanetary space and in situ measurements of solar wind plasma and high energy solar particle events. The L5 point is an appropriate position for making side-view observations of geo-effective coronal mass ejections and interplanetary plasma clouds.

Here, we describe briefly the mission plan and the ongoing BBM development of important subsystems such as the wide field coronal imager (WCI) and the mission processor. The WCI will have a large CCD array with 16-bit sampling, to achieve a dynamic range of several thousand in order to detect very small deviations due to plasma clouds under zodiacal light contaminations a hundred times brighter than the clouds. The L5 mission we propose will surely contribute to the construction of an international space weather observation network.



*Keywords:* International space weather program; Space weather forecasting; L5 mission

## 1. Introduction

Space weather research requires carrying out comprehensive observations and obtaining a better understanding in regions ranging from the Sun to the Earth's upper atmosphere. Space weather forecasting requires the application of various techniques, including the construction of networks for observing the space environment from space- and ground-based observatories and the development of operational models and algorithms. Key issues in this field are related to solar energetic particle (SEP) events and geomagnetic storms. Coronal mass ejections (CME) and the interplanetary shocks, often drive are considered to be the most important drivers of SEP events and large geomagnetic storms. We proposed a plan, the L5 mission, to observe CME propagation, and along the way to ascertain the physical process caused by their interaction with the ambient solar wind plasma. The L5 mission is an interplanetary space weather observation platform, which will be deployed at the fifth Lagrangian point of the Sun–Earth system (the L5 point). One of the main objectives of the mission is to achieve side view remote sensing of CMEs propagating toward Earth along with their solar source over a period of several years near solar maximum. The mission will also carry in situ instruments of solar energetic particles and solar wind plasma to allow multi-point observations with other interplanetary spacecraft. Since we first proposed the L5 mission we have been studying this concept

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in cooperation with National Space Development Agency of Japan (NASDA), Institute of Space and Astronautical Science (ISAS) and the scientific community of Japan. The development of critical sub-systems of the L5 mission was started within the framework of NICT's space weather research. The objectives of the L5 mission are observing space weather phenomena, conducting experiments on space weather forecasting, and making contributions to international initiatives for space weather observation networks such as the International Living with a Star (ILWS) program. In this paper, we provide an overview of the L5 mission concept along with the status of advanced research, and the development of important sub-systems that relate to the proposed project.

## 2. Observation with the L5 mission

### 2.1. Space weather observation with the L5 mission

The L5 mission will enable us to dramatically improve our understanding of space weather phenomena, solar terrestrial relations, and inner heliosphere physics. This section briefly reviews the important research and observation targets that are the objectives of the proposed mission.

### 2.2. Flare and CME initiation mechanisms (Energy build-up and release)

Yohkoh observations reveal the primary process of flares as magnetic reconnection in the solar corona. The next two important questions are how flare and CME energy is built up in magnetic field, and what the key mechanisms are that lead to magnetic reconnection. Observation of the three-dimensional structure of the upper atmosphere of sunspot groups and active regions is imperative for understanding flare/CME build-up. Coordinated observation with the L5 mission and a satellite near Earth would be a powerful tool to accomplish this goal.

### 2.3. CME propagation and high energy particle production

Interplanetary shock waves induced by traveling CMEs are considered to be a major factor in SEP production and acceleration. Observations of CME propagation, and the changes that occur in it along the way, are considered to be important for understanding the particle acceleration mechanism. For example, a hybrid acceleration model for SEP events has been proposed based on recent observations of particle composition. In the hybrid model, seed particles are produced at solar flare sites, and the particles are trapped and further accelerated in the shock waves induced by traveling CMEs (Reames et al., 1990; Lee, 1997). Observation of CMEs and shock wave generation, with its relation to original flare sites, will give an important clue to better understand the involved particle production and acceleration mechanisms.

The generation and evolution of CME-driven shock waves and the distribution of high energy particles are key issues for understanding SEP acceleration and propagation. High sensitivity remote sensing of interplanetary CME clouds with a wide field of view imager is required to track their propagation from the Sun to Earth. In situ plasma observation and radio remote sensing are important for understanding the detailed structure of CMEs and their interaction with ambient solar wind plasma including accelerated particles. Coordinated remote and in situ observations will provide a unique opportunity to clearly delineate CME and shock structure and to establish a data analysis scheme of CME remote sensing data.

### 2.4. Development of space weather prediction scheme

Nowadays, geomagnetic storms can be predicted, with some degree of accuracy, roughly 1 h in advance by using the ACE spacecraft's real-time solar wind data. Side-view observations from interplanetary space of CMEs traveling toward Earth, such as those from the L5 point, are crucial for predicting storms with more leading time. Therefore, studies on algorithms to derive physical parameters from remote sensing data are also an important target of the mission. Hence, collaboration with in situ missions, such as the inner heliosphere sentinel planned in LWS, is essential to enhance the results produced by the L5 mission.

Another important theme in space weather forecasting is a leading patrol of hazardous active regions. If the probability of an SEP event could be evaluated in advance sufficient time would remain to make steps to significantly reduce radiation risks for astronauts. It is difficult to predict solar flares and SEPs from observation or model estimation, mainly because the mechanisms of solar flares and SEPs have not yet been revealed. However, if we can detect SEP producing and/or flare producing active regions while they are still behind the solar limb, forecasters would be able to issue alerts three or four days in advance. Monitoring active regions behind the limb would also be useful for forecasting short wave fadeouts caused by flares on the east limb.

## 3. Wide field CME imager

### 3.1. The WCI detector

Tracking a CME to large distances from the Sun requires measuring a very large dynamic range of intensity. The brightness of CME clouds traveling through interplanetary space rapidly decreases as the distance from the Sun increases. Eventually, the brightness will be approximately 10–15 times that of solar brightness. Moreover, the wide field coronal imagers (WCIs) CME cloud observations will be made against the background of strong zodiacal light. For a large dynamic range, the system requires a large detector SNR and a low level of unwanted light on the image planes. CME clouds at 1AU distance from the Sun are estimated to be more than one hundred times fainter than the background that is composed mainly of zodiacal light and starlight (Fig. 1). The estimate of CME brightness is taken from Jackson et al. (1991) and of the zodiacal light intensity from Allen (1973).

Under strong background light, the relation between SNR and (a) the ratio of background and target intensity and (b) the electrons created by the detector is

$$S/N = \sqrt{S \cdot \frac{B_t}{B_b}},$$

where $S$ is the signal from the target, $B_t$ is the brightness of the target, and $B_b$ is the brightness of the background.

If we substitute 300 for $B_t/B_b$ and 100 for SNR, we find that 1E6 electrons coming from CME itself are required to achieve a SNR of 100. However, most electrons accumulated on the CCD are from the background zodiacal light and starlight instead of from a CME cloud. For a full-well CCD with 200,000 electrons full-well, signals produced by photons from a CME cloud achieve a level of 6.7E2 electrons. This simple calculation shows that signal integration of 1500 pixels is necessary to collect signals from a CME cloud. Thus, we need a high precision detector with a large format CCD device to get a high SNR.

Table 1 shows the specifications of the CCD detector. Two back-illuminated CCD tips manufactured by EEV will be used for mosaic CCD detectors with 16M pixels. A rad-hard FPGA with 20,000 gates will be used for the CCD drive including clock generation, and a 16-bit ADC with radiation tolerance will be used for A/D conversion of read-out data. The read-out clock speed is 100 kHz to reduce read-out noise as much as possible.

### 3.2. WCI optics

To get a CME cloud image, light from starlight, zodiacal light, and the galaxy's light should be subtracted from the onboard pixel summing. The subtraction of starlight is preferable as a means of detecting faint CME signals. For onboard data subtraction, high performance optics is required so that stellar images will not be blurred over pixels. However, to avoid scattered light and flare light produced in the lens system itself, the number of lens system surfaces should be minimized as much as possible. In general, for wide field optics with high quality imaging performance, optical designs with many surfaces are required to reduce aberrations. That

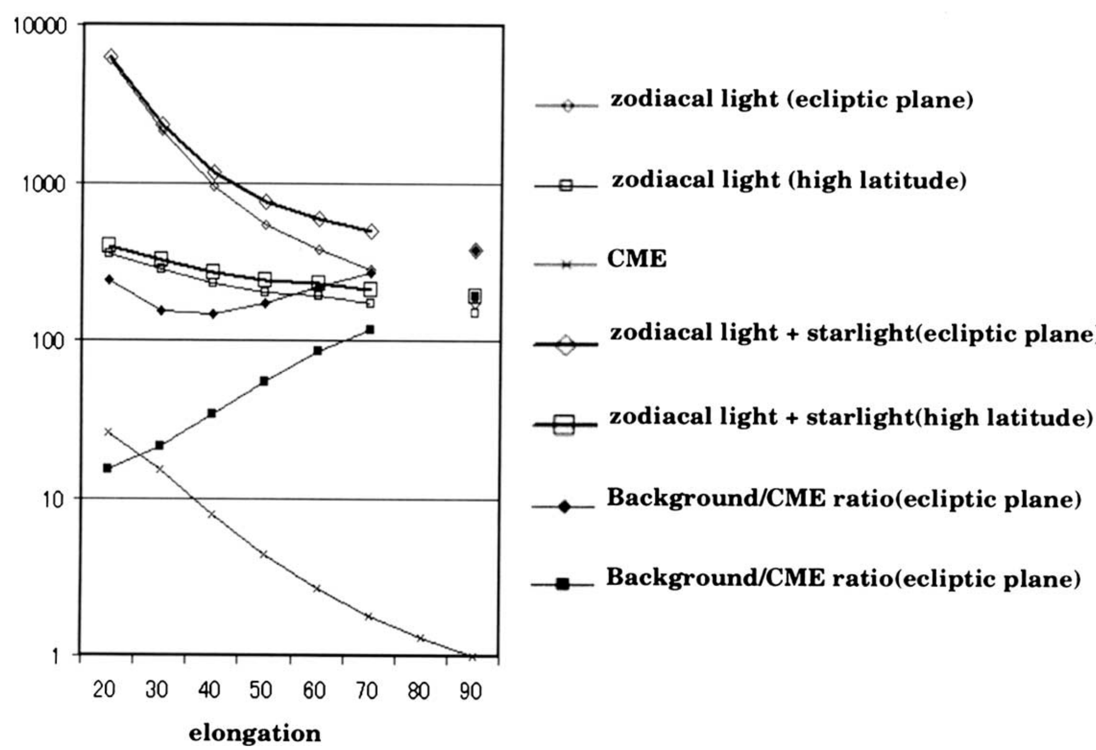


Fig. 1. Comparison of background (zodiacal light and starlight) and CME signal.

Table 1
Specifications of CCD sensor

| | |
|---|---|
| Full-well | 2E5 electrons/pixel |
| Quantum efficiency | 90%@500 nm |
| Effective pixel number | 4096 * 4096 |
| Pixels size | 15 μ * 15 μ |
| Dead-out | Dual integration method |
| Depth of pixel | 16 bit |
| Operation temperature | 213 K |
| Read-out clock | 100 kHz |

is, there are conflicting requirements between a wide field of view with high image quality and a low unwanted light design with a small number of surfaces. To solve this difficulty, we designed a wide field optics with a five lens element including three aspheric surfaces. Fig. 2 shows the optical design of the aspherical system. Ray tracing analysis shows that the required performance of the spot diameter less than the CCD pixel size (15 μ) can be expected. To achieve this requirement, the design wavelength is set at 700 nm because the chromatic aberration decreases at longer wavelengths. In this design, the foremost lens elements, which will be directly exposed to the space environment, are made of silica. These foremost silica elements play a major role in radiation blocking.

## 4. Mission processor

### 4.1. Need for a high performance mission processor

The L5 mission plans to carry high performance data processors for onboard data analysis of the large format image data. We have studied the concept and feasibility of a high performance mission data processor (MP) through the use of high performance commercial components, including environmental tests of key components. The needs of MP are summarized as follows:

*Reduction of data transmission volume by data selection*: The L5 mission will be deployed at 1AU far from Earth making it difficult to transmit raw image data produced by a large format image sensor. Thus, it will be necessary to reduce the total volume of the data to be transmitted to ground stations. Consequently, the L5 mission will carry a high performance onboard data processor for intelligent selection of data to be transmitted to the ground station based on the results of onboard data analysis. To achieve this, a high performance MP for onboard data analysis of large format image data analysis will be required.

*Real-time transmission of data and alerts for space weather operation*: Goals of the L5 mission include experiments on observation and alerts for space weather disturbances and transmission of key parameter data from the L5 point in real-time. For these purposes, a high performance MP will be required for onboard data processing to achieve automatic event detection and real-time data analysis.

*Planned experiments for the autonomous space weather alert module*: Experiments are planned to develop a capability of the autonomous space weather module that would permit switchover to a mode with greater tolerance to SEU when a space environment disturbance above a certain magnitude is likely to occur. Such in-orbit experiments will require powerful data processing capabilities, as well as an operational environment that permits the execution of various experimental functions, such as in-orbit software updating and installations.

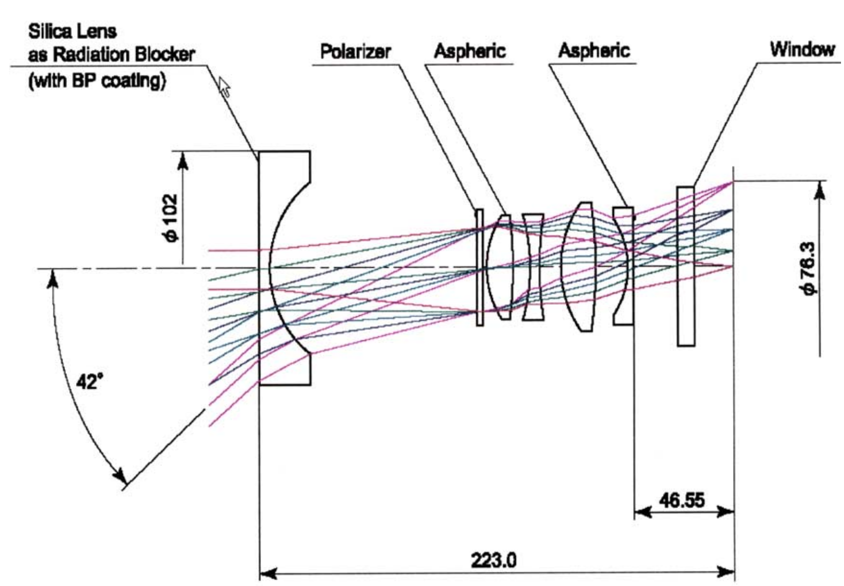


Fig. 2. Optical layout of WCI.

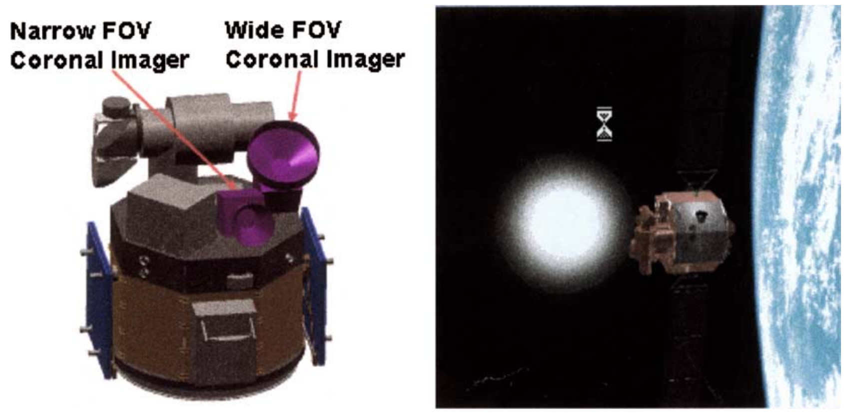


Fig. 3. Schematic design of small satellite for orbital demonstration experiment.

### 4.2. Mission processor hardware

Our plan for this project is to use a commercial real-time operating system (RTOS), which are now widely used for embedded system applications. A multi-process type operating system (OS) such as an RTOS should be better than a multi-thread type OS due to its robustness. With a multi-process type OS, when an application software hangs up due to an error, only the application experiencing the problem is terminated or interrupted and the other processes, including the kernel, are not affected. A trade-off study performed among many commercial RTOSs revealed that QNX is currently the most suitable candidate for the application in this case. Recently, QNX has been gaining popularity as a means to achieve ground-based observation system control in scientific applications related to space weather forecasting. This means that many researchers can participate in the development of the application software for on-board data processing.

### 4.3. Future plans

To achieve ground-based observation system control for the L5 mission, a relatively small spacecraft of approximately 450 kg with instruments will be sufficient. A mission profile study performed shows that the objectives of the L5 mission can be realized with a medium size launch vehicle or with the dual launching of H2-A class rockets.

Since WCI and MP are challenging instruments, actual orbital demonstrations are required before the L5 mission can actually be carried out. NICT plans orbital demonstrations of critical instruments for the L5 mission together with those for inter-satellite optical communication experiments. The proposed schedule for the demonstration mission with a small satellite is around the year 2007. After that, we will implement the L5 mission near the next solar maximum of 2011 see Fig. 3.

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