8

Research Trends in Space Environment Observation and Fluctuation Monitoring

TERUHISA TSUJINO
General Unit

1 Introduction

The extent of human activities has evolved starting from self-sufficient small communities to nations, and further, to a global level. Today is an age where the development and utilization of space is gaining momentum. As this development proceeds, it has become increasingly clear that the extraterrestrial space environment such as solar activity, the magnetosphere of the earth, space objects, etc. is very much concerned with our existence and our activities on the surface of the earth.

This article introduces trends in recent research on space weather, space debris and Near Earth Asteroids (NEAs), which are typical objectives of observation to gain information on the space environment surrounding the earth. Based on these objectives, I also present some proposals for the guiding policies required for future space exploration.

2 Space weather

2-1 Space weather and its forecasting

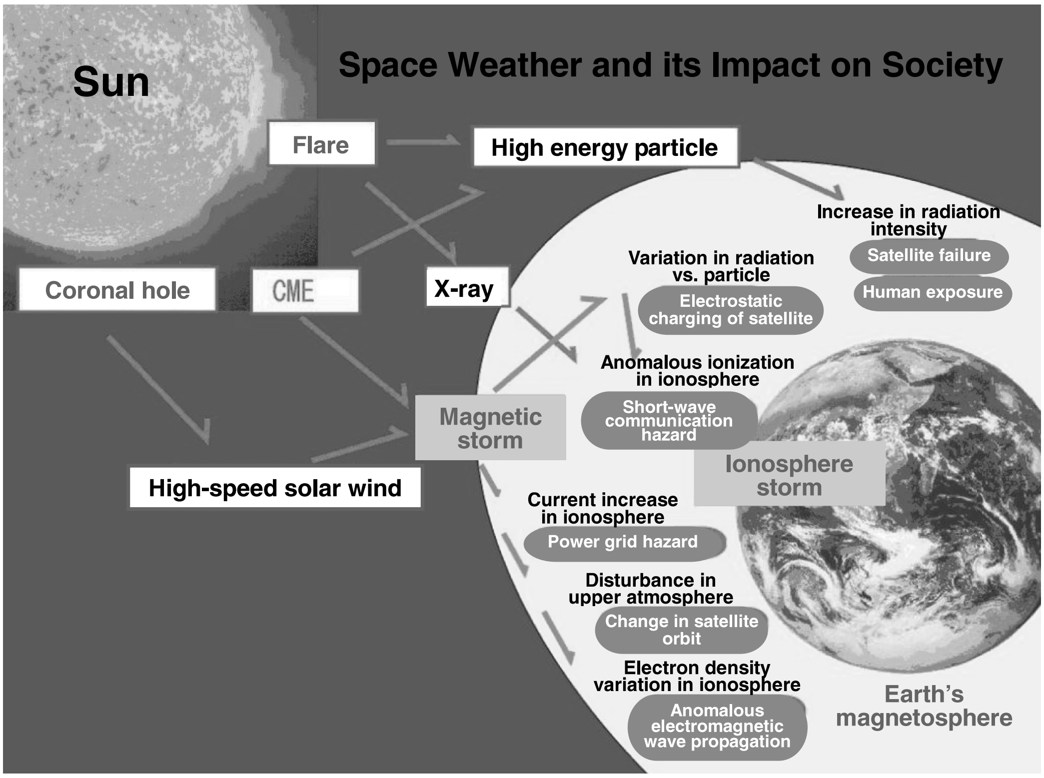
“Space weather” collectively represents fluctuation in environmental factors, including cosmic radiation and electromagnetic plasma that occur in space ranging from the electromagnetic sphere to the atmosphere. These factors naturally affect development activities in space, just as the wind and rain affect our lives on earth, hence the term “space weather.”

Beginning October 23 of 2003, one of the largest sunspots ever known appeared on the surface of the sun, producing a series of enormous explosions (called “flares”), and the earth suffered serious geomagnetic storms. The National Oceanic and Atmospheric Administration (NOAA) issued warnings against the failure/malfunction of: commu nication/broadcasting systems, electronics devices, satellites, and systems using GPSs (global-positioning systems) such as car navigation systems. Solar wind shock waves reached the earth’s magnetosphere interface at 15:25 (GMT) of October 24 and, about 15 minutes later, triggered the creation of one of the most extensive aurora in the polar regions. The observed magnetic field fluctuation during this period was as wide as 2,000 nT (nanoTesla). (The normal intensity of terrestrial magnetism in the polar regions is around 50,000 nT, and fluctuation caused by aurora is usually around 500 nT.)

The mechanism that produces these phenomena is generally understood to be the interaction between solar activity and the earth’s magnetosphere as depicted in figure 1. We have gained a fairly good understanding of the mechanism that drives changes in space weather. In addition, the global deployment of ground observation equipments has enabled the accumulation of necessary data. These aspects have enabled us to some extent to forecast environmental fluctuation in space, or to give “space weather forecasting”. Globally linked efforts for better forecasting have already begun.

One of the most important aspects of space weather forecasting is to secure satellite operation in orbit. The measures that have hitherto been implemented in Japan and other countries include: (i) activation of safe-mode satellite operation (shutdown of lower-priority

Figure 1 : Concept of Space Weather



devices, etc.); (ii) evacuation of astronauts to safer places in the spaceship; (iii) temporary postponement of launching; (iv) changing solar panel orientation; and (v) temporary shutdown of communication and observation tasks. More timely and appropriate measures will be enabled through improving accuracy of space weather forecasting and providing closely linked information systems.

2-2 Space weather observation

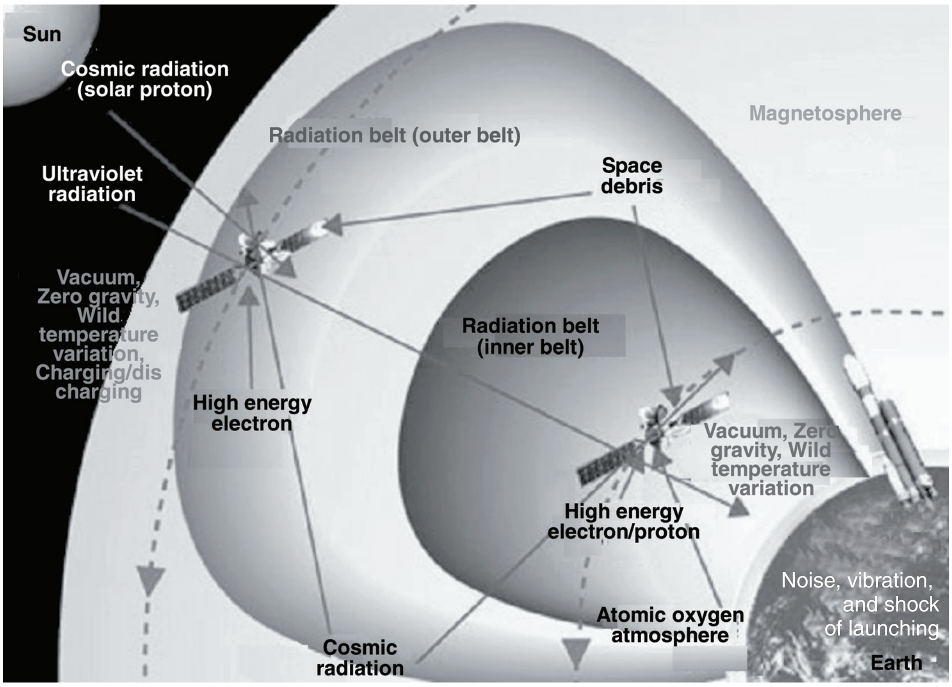
Explosions on the surface of the sun produce an enormous amount of high-energy charged particles, radiation, and gigantic plasma clouds into space, a portion of which are approaching the earth. Lives on the earth are protected from these threats by the atmosphere and the magnetic field produced by the earth (the earth's magnetism) since the earth itself is a huge magnet. The region of space surrounding the earth in which the earth's magnetism has strong influence is called "geospace" In particular, the area beginning from the transition area in which the neutral atmosphere gradually changes into ionized gas (altitude ≤80km) and further, into the magnetosphere filled with magnetic plasma (up to 70,000km), has a strong influence on human activity on the surface of the earth.

(1) Observation of space radiation environment

As shown in Figure 2, there is a radiation belt in the geospace region, consisting of an outer and an inner belt, and is called the "Van Allen Belt." The mechanism of the formation of and fluctuation in this belt requires systematic study including that on the underlying dynamics of the magnetosphere and the physics of particle acceleration. Space radiation, especially the abnormally intense radiation associated with explosions on the surface of the sun, can cause space ships to malfunction. Disabled space ships are destined to become space debris.

Various countries have launched satellites to measure the space radiation environment. The geostationary astronomic observation satellite, HIPPARCOS, launched by the European Space Agency (ESA) in 1989 after successfully entering transfer orbit, but failed to enter geostationary orbit due to apogee kick motor malfunction. This failure accidentally forced the satellite to pass through the Van Allen Belt at high frequency, bringing an unexpected wealth of information related to the space radiation environment. In Japan, the MDS-1 satellite was launched to intentionally remain in geostationary transfer

Figure 2 : Radiation Environment and Cosmic Ray Hazards in Space



Source:Provided by NICT

orbit to collect radiation-tolerance data on consumer electronic devices.

To gather information on the effects of fluctuation in the radiation environment of satellites, it is desirable for many satellites with different orbits to be installed with radiation-measuring equipment. The development of smaller and lighter sensors that can be mounted on various satellites for other missions and the launch of as many satellites as possible are effective methods of achieving this objective.

The major energy ranges for future investigation include the 0.01-20 MeV range for electrons and the 0.1-500 MeV range for protons.

(2) Observation of the magnetoplasma environment

The magnetoplasma atmosphere produces eddy currents in mid-latitude regions on the earth as well as three-dimensional currents flowing along the line of magnetic force. Fluctuation in these currents causes fluctuation in the earth's magnetism and, in high-latitude regions, gives rise to aurora. Thus, accumulating data on the global magnetism of the earth will provide, using proper inverse-transformation techniques, the possibility of forecasting fluctuation in the magnetoplasma environment in the ionosphere 100km above the earth's surface.

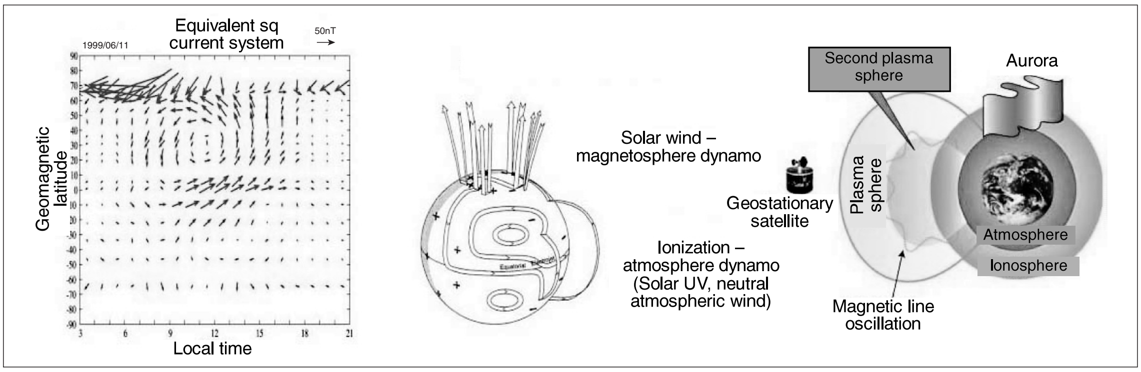
A project is in progress at Kyushu University in which MAGDAS (Magnetism Data Acquisition System) is being deployed at 54 observation points in Pacific Rim regions to transfer global magnetism data to the university for real-time analysis. The data are used to make imaging in the three-dimensional current system in the vicinity of geospace and to monitor the atmospheric plasma environment.

A pair of magnetism observation points is assigned to each location. The gradient method is used to measure plasma density parallel to the line of magnetism passing through the center of the two points.

(3) Observation of the earth's magnetism

The earth's magnetism provides the earth with effective protection against the harsh environment of space. It changes not only in the short term, for example, on a daily or monthly basis, but also in very long term; we know that the direction of the earth's magnetism inverted around 700,000 years ago, and comparison with data of several hundred years ago reveals that the earth's magnetic pole has drifted. The coming millennium, beginning with the 21st century, will witness expanding human activity in space on the one hand, and the global weakening of the earth's magnetism on the other. There are a

Figure 3 : Magnetic Field Observation in Geospace from Geomagnetism Variation Data Using the MAGDAS System

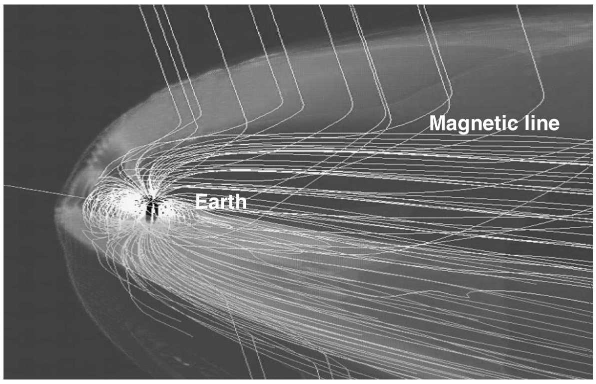


Left Equivalent current flow pattern in the ionosphere (100 km above the ground) estimated from collected magnetic field data.
Center Estimated global three-dimensional current system in geospace (Richmond, 1998)
Right Plasma density distribution in near space: estimated from magnetic line oscillation.

Source: Provided by Kyushu University

number of concerns about the latter, including: exposure of the human body to cosmic rays and charged particle flux from the sun, electric wave hindrance, satellite failure due to cosmic ray exposure, and power grid shorts in high-latitude regions. An anomalous decrease in the earth's magnetism has already been reported in Brazil, and adverse effects on the earth's environment and the earth's inhabitants due to the abnormally high intensity of cosmic ray fallout in these areas are appearing.

Figure 4 : Example of Magnetosphere-ionosphere Global Simulation



Source:Provided by NICT

2-3 Trends in numerical simulation

The ever-increasing performance of computers and their decreasing price have enabled the application of numerical simulations in various aspects of physical phenomena. In the area of space environment, numerical simulations have achieved to understand a systematic, global view of such phenomena as electromagnetic energy transport processes in response to the solar wind fluctuation taking place in a complex system including the ionosphere, and the dynamic characteristics of the linked system consisting of the magnetosphere and the ionosphere. This will be an essential tool for studying the complex system consisting of the magnetosphere and the ionosphere, which is required for space weather forecasting. Further refinement of programs and numerical simulation models are required.

In addition to magneto-ionosphere-linked models that simulate the motion of charged particles using fluid dynamics approximation, direct trajectory calculation for each charged particle on a global scale has also become a reality thanks to modern techniques of numerical calculation and huge computer power. Global simulation using this methodology has provided us with a mutually consistent understanding between magnetosphere-ionosphere perturbations, fluctuation in convection, and particle effects (See Figure 4).

2-4 Global trends for space weather forecasting

(1) International space weather observation project

The Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) has urged its member countries to cooperate in studies to minimize the adverse effects of cosmic radiation and charged particles from the sun. These studies include forecasting space environment fluctuation and evaluating its effect on the environment on the earth that supports human activity.

Beginning in 2004, SCOSTEP launched a new international observation study project called the Climate And Weather of the Sun-Earth System (CAWSES). Many countries including U.S.A., Russia, European countries and Japan are now preparing concerted research into space weather observation and forecasting.

In U.S.A., a space weather forecast simulation system will be developed starting in 2004. The five-year project sponsored by the National Science Foundation (NSF) will be led by Boston University[1].

Spaceship malfunctions are thought to be induced mainly by abnormal increases in radiation and re-creation of / fluctuation of the radiation belt. New theories, such as high-energy particle acceleration by ultra-low frequency waves (ULF), have been proposed for a consistent explanation of this phenomenon by the University of California (UCLA) and the British Antarctic Survey (BAS).

In Japan, tasks will be allocated to multiple research institutes according to the feature of the task and the organization, and each institute will bear the responsibility of providing observation data in that particular research area. The research institutes participating in the project include: National Institute of Information and Communications Technology (NICT)[2], Japan Aerospace eXploration Agency (JAXA)[3], Metrological Agency Magnetic Observatory[4], Tokyo University[5], Nagoya University[6], Kyoto University[7], and Kyushu University[8]. A systematic, closely linked observation research network will be constructed to effectively contribute to the global effort.

(2) Major observation systems in Japan

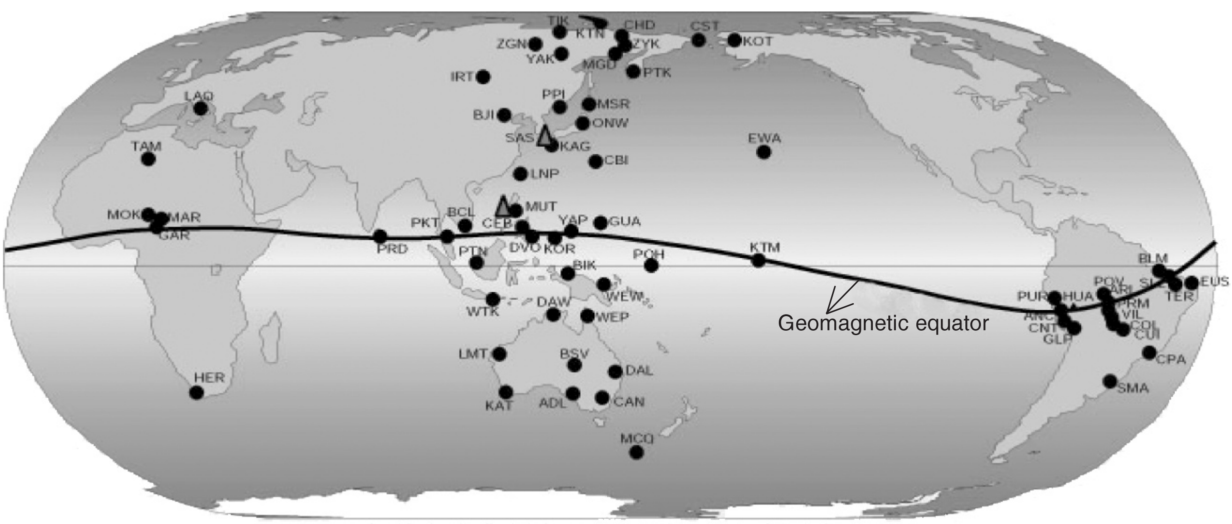
In Japan, Kyushu University led an international research project in collaboration with the Far Eastern area of Russia and developing countries in the equatorial region in the duration of 1991-2003 to construct the Pacific Rim geomagnetism observation network (see Figure 5).

Global networks such as this one are instrumental in enabling the three-dimensional imaging of current systems in geospace around the earth. Existing systems, however, cannot provide sufficient spacial resolution. To enhance system performance, the following challenges must be addressed:

i) A sufficient number of geomagnetism observation pairs and ionosphere observation radar networks must be installed to image the three-dimensional current system and to monitor the atmospheric plasma system. A high-capacity data-processing system is also required for the real-time analysis of these data.

ii) An imaging system to visualize the electromagnetic environment in geospace

Figure 5 : Pacific-rim Geomagnetism Observation Network



Pacific Rim Geomagnetic Observation Network: 54 data stations

Source: Provided by Kyushu University

must be developed. It will continuously visualize the fluctuating three-dimensional current system, thus serving for the real-time monitoring of the electromagnetic environment in geospace. The remote sensing of high-energy plasma particle distribution in space near the surface of the earth, which is inaccessible from satellites, will also be covered by this system.

iii) A system capable of monitoring interactions between geospace and the ionosphere must be installed by comparing data obtained from the multiple point observation data of plasma density in the ionosphere. Exact-time information is essential to activate the system. Although GPS ground receiving stations have been distributed over a number of areas around the world, additional effort is still required to fill the still vacant areas.

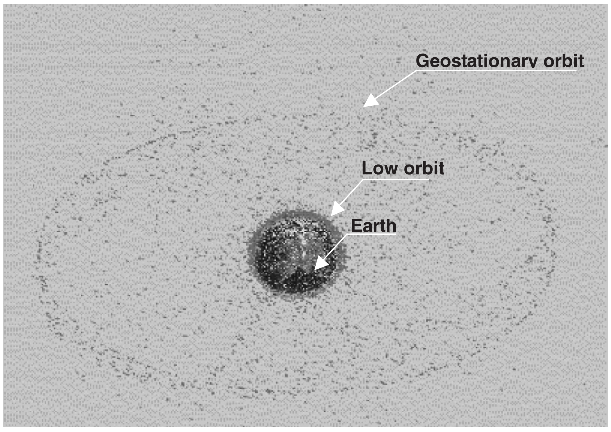
Advancement of "space weather" research will enable more accurate, real-time "space weather forecasting." To achieve this, the well-organized combination of a number of factors are required including: the compilation of the past results of global electromagnetism research conducted in various countries over many years, the continual accumulation of observation data, and the introduction of innovative simulation techniques to handle complex systems.

3 Space debris

3-1 What are space debris?

Since the beginning of space exploitation activities, innumerable rockets and satellites launched into space, and the remains of upper stages of rockets and decommissioned satellites have finally become rubbish in space, or space debris. As shown in Figure 6, the distribution of space debris is concentrated in lower earth orbit, but it also extends into middle and geostationary orbit and even into its exterior. Low orbit satellites (altitude ≤1,000km) that have been abandoned due to unexpected accidents, or that have been decommissioned after completing their tasks, are still orbiting as space debris around the earth at a speed of about 7km per second.

Figure 6 : Distribution of Minute Space Debris



Source: Provided by Kyushu University

Collision with these pieces of debris seriously damages satellites and the international space station, and is also considered to constitute a grave threat to astronauts performing tasks outside the spaceship.

Space debris orbiting the earth at an altitude of higher than 1,000km has little chance of falling to the earth. Lower-orbit debris at an altitude of higher than 600km circles the earth for 20 years before it falls. Without implementing effective measures, continuing conventional space development plans will simply increase the amount of space debris. Promoting fundamental research into methods for the observation, mitigation, removal, and reduction of space debris is becoming increasingly urgent.

3-2 Threat of space debris

In recent years, examination conducted on recovered satellites and the windows of space shuttles after returning from missions has revealed numerous traces of collisions, indicating that space contamination by numerous pieces of minute pieces of space debris (sub-millimeters in diameter) is even worse than we previously estimated. Ground observation stations cannot detect these tiny pieces of debris. They are generally produced by the explosion of satellites in orbit at the last stage of rocket launch. Although very tiny, a piece of space debris orbiting at a speed of 7km/sec is capable of exerting an enormous impact (Collision with a 1-cm-diameter piece of space debris at low altitude is roughly equivalent to a collision between two cars running at 60km/hr). Collision with a satellite in operation could be fatal. A greater-than-1-mm-diameter piece of space debris is a threat to astronauts during extravehicular activities, and a piece of debris greater than 1cm could cause serious damage to an international space station.

The proliferation of space debris will be a serious hindrance to future space activities. How to avoid this problem is a major theme on the space development projects.

3-3 Observation of space debris

Large pieces of space debris (diameter >= 10 cm) in lower orbit can be tracked from ground radar stations and have been catalogued in a database. Their trajectories in orbit can be affected by external forces, or perturbation, such as air drag and gravitational pull from the sun and moon, and thus need constant tracking and data update in the trajectory database. Recently, size distribution information of relatively small pieces of space debris has been obtained from surface inspection conducted on several satellites recovered from lower orbits (See Figure 7). These satellites include LDEF (U.S.A), EURECA (Europe) and SFU (Japan).

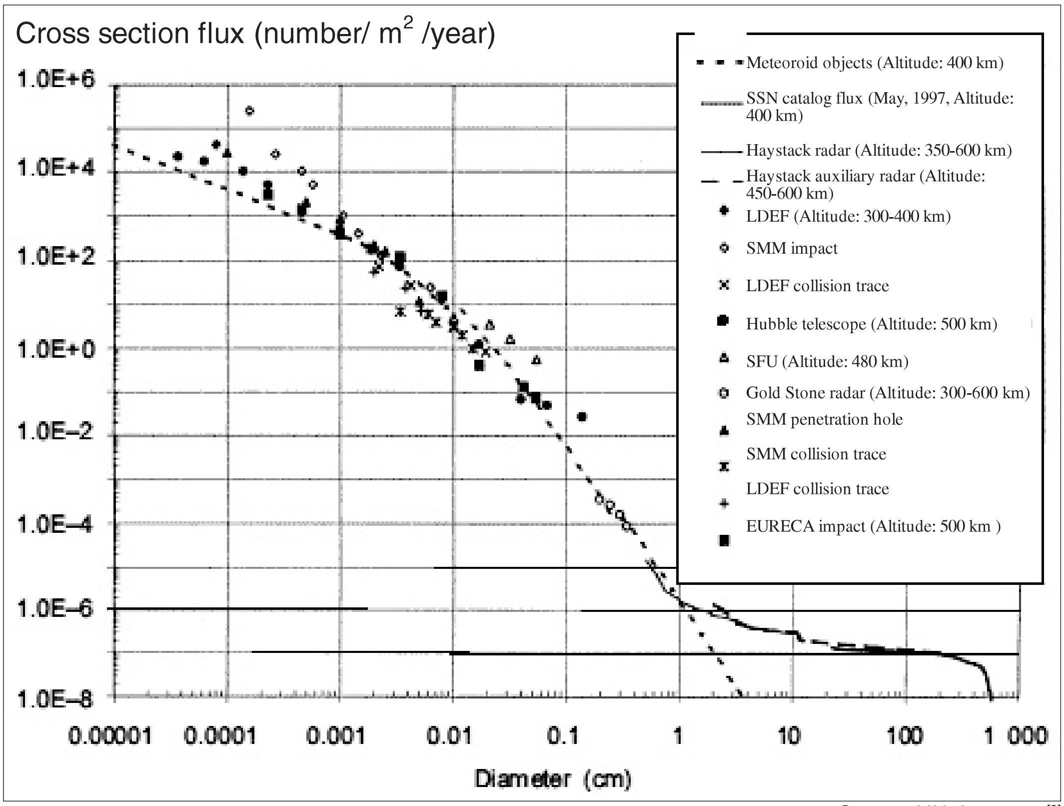
Observation data of medium-sized space debris, between several millimeters and several centimeters, and information on medium to high earth orbits are completely insufficient. The development of sophisticated observation technology is required to obtain the necessary information on these medium-sized objects, flying in medium and high earth orbits, to complete the space debris database.

In line with the need for international cooperation in space debris monitoring, the Inter-Agency Space Debris Coordination Committee (IADC), which was established in April 1993, urged its member countries in 1999 to implement space debris observation campaigns to collect information in the vicinity of geostationary orbits and lower earth orbits. In response to this, each country conducted a space debris survey using optical telescopes and ground radar facilities.

(1) Optical observation of Space debris

Using an optical telescope, relatively high earth orbit space debris can be monitored by reflected sunlight. Because of the nature of this method, observation can only be performed at night.

Figure 7 : Space Debris Flux Model



Source: UN document[9]

Table 1 : Optical Observation Facilities for Space Debris: Performance Comparison

Nation	Operating Organization	Primary mirror diameter (m)	View angle (degree)	Observable magnitude(star magnitude)
U.S.A.	NASA	3	0.3	21.5
Japan	JAXA/JSF	1	3	19.5
Swiss	Bern University	1	0.5	19.5
Russia	RSA	1	0.2	19
France	CNES	0.9	0.5	19
U.K.	Greenwich Observatory	0.4	0.6	18

Source: UN document[9]

Space debris circulating in lower earth orbit fly for most of the night in the shade of the earth and do not reflect sunlight at all, limiting the observable period to a few hours towards sunset and before dawn.

Space debris in the vicinity of geostationary orbit can be observed using the optical telescopes, except for a certain period around the vernal and autumnal equinox. The National Aeronautics and Space Administration (NASA) focuses on observing space debris of greater than 50 cm, and the European Space Agency (ESA), on space debris of greater than 20 cm. In Japan, a space debris survey being is conducted at the Bisei Spaceguard Center (Bisei Town, Okayama Prefecture). The system can catch space debris of greater than 50 cm, and efforts are being made to extend its capability to the 20-cm range.

Table 1 summarizes the comparison of telescopes used for space debris observation in major countries. The wider the view angle, the wider the space region that can be simultaneously observed. Although the telescope used in Japan has a smaller-diameter primary mirror compared to the telescope used in the U.S.A., it has a much wider view angle. In addition, the telescope at Bisei is used solely for space debris observation, enabling greater availability and better conditions than systems in other countries.

Considering the fact that no satellite has ever been recovered from geostationary and medium-to-high earth orbit, ground-based optical observation is very important.

The development and systematic operation of an enhanced optical telescope that enables the observation of smaller pieces of space debris is instrumental in enriching the information obtained using the optical method.

(2)Radar observation of Space debris

Using a ground radar station, space debris can be detected. The radar emits electromagnetic waves, and detects the waves reflected by space debris again on the ground. Due to the nature of this method, detection capability is limited compared to the optical method; the practical detection range is limited to about 1,000km.

NASA has started experimental observation to cover objects as small as 1cm using the military facility, Cobra Dane, located in the Aleutian Islands. Because of the limitation described above, the results obtained so far are limited mainly to larger debris (≥ 10cm). The system in Cobra Dane was originally installed to survey missile launches from the former Soviet Union, and is thus located in a high-latitude region (52.7, North Latitude). Because of this, the system cannot detect space debris with low orbital inclination.

ESA uses the radar that belongs to Forschungsgesellschaft für Angewandte Naturwissenschaften (FGAN), which can track pieces of debris as small as 2-3 mm in diameter. However, the effective view angle is severely limited because the radar is of a parabola format and cannot instantaneously scan a wide range of electromagnetic spectra.

In Japan, an experimental radar system for space debris observation started operation in April 2004 at Kamisaibara Spaceguard Center (Kamisaibara Village, Okayama Prefecture). (See the topics in the April 2004 issue.) This is the only radar system in Japan installed solely for space debris observation capable of continuous service. The system is experimental in nature, and one of its important missions is to gather operational/technical information for the future construction of a practical system capable of detecting small (≤ 10cm) pieces of space debris flying at relatively low altitudes. The realization of this unique observation facility is awaited worldwide.

Compared with the optical telescope method, which is accessible even by an amateur astronomer with a small-diameter telescope, the radar system requires huge system investment that can only be realized as a national-level project. The experience and results obtained from the Kamisaibara Spaceguard Center will accelerate the progress of the radar method in Japan, which has hitherto lacked systematic engagement. Based on these results, it is desired that an enhanced infrastructure comparable in performance to Cobra Dean and FGAN in low-latitude regions be constructed, enabling space debris observation that outperforms that of other countries.

(3) Space debris observation from Satellites

The use of satellites as instruments to observe space debris has not yet been realized. However, once it is put into practical use, satellites will provide a wealth of information, including the capability to measure tiny pieces of debris that are not accessible using the ground-based observation method. Several methods have been proposed for space-born measurement including PVDF, plasma, and the ion method. These methods are all devised for counting the number of collisions with tiny pieces of debris.

The satellite is equipped with wide solar panels to provide power to the on-board equipment. Geostationary satellites, for example, usually have a large solar panel exceeding 100 m^2, and collisions with tiny pieces of debris often take place on the surface of the solar panel. Taking advantage of this fact, solar panels can be used as collision detectors by installing an on-board surface inspection system (camera) to monitor the surface of the solar panel arrays.

Obtaining images with accurate collision imprints for analysis plays an important role in this method. A group in Kyushu University has already finished a conceptual design for an on-board surface inspection system, and implemented it as a prototype model consisting of a camera and image-processing system. The model was tested and has proved successful in searching for a collision imprint by scanning the surface using an on-board camera, and taking a close-up image of the imprint. This sequence is carried out automatically.

3-4 Mitigation of space debris

Even in the event of collision with a piece of space debris, the spaceship must continue its mission. Research on protection and damage control against space debris collision is also in progress. An example of this research is being implemented in the Japanese experimental module “Kibo” (meaning ‘Hope’), to be incorporated in the front-end (traveling direction) of the international space station. The module is equipped with a bumper to absorb collision impact, and it prevents the penetration of debris smaller than 1cm.

For larger debris that the bumper cannot ddefend, the international space station will take evasive action (for example, change of altitude) by continuous calculation of the relative position between the space station and the debris.

3-5 Reduction and removal of space debris

The most fundamental approach to secure safe human activity in space in future should be to prevent space contamination from worsening, as well as the workaround method (e.g. evading collision) described in the previous section. The guiding principle for this should be to prevent generating space debris. The design and development of satellites and launch vehicles that do not generate space debris is of utmost importance.

Japan has taken the lead in adopting this principle among a number of countries and implemented debris-reducing measures for its upper stages of rockets and satellites, which are evaluated highly by other countries.

An example of this approach is incorporated in geostationary satellites; decommissioned satellites are programmed to move to higher orbit, preventing space debris being left in geostationary orbit, which is a valuable resource for future reuse. The method of space debris reduction has become one of the major themes in the '90s; Japan adopted this approach ten years before this on its own initiative.

Another advanced technology now being considered to reduce the amount of space debris includes the use of lasers to modify trajectories, finally forcing the debris to fall into the atmosphere. It seems, however, that it will take a long time before this method is applicable.

4 Near Earth Asteroids: NEAs

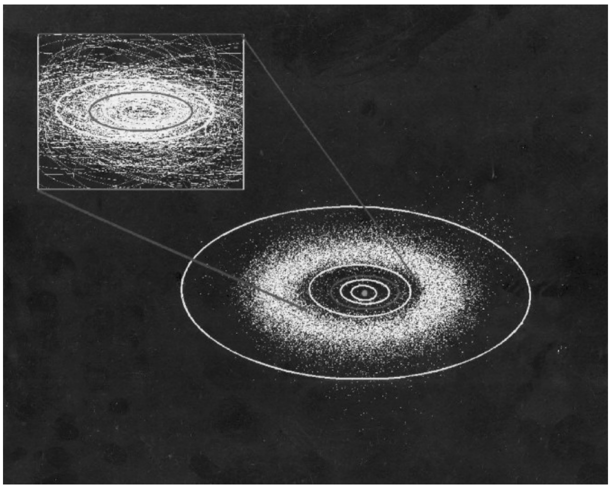
There is a belt of scattered asteroids (asteroid belt) between Mars and Jupiter. The first asteroid was discovered on the 1st of January, 1801, and there are many different theories concerning the origin of the asteroids; one theory says that they are small planets that could not grow to large planet at the infant stage, and another says that they are debris generated by the explosion of a planet. Until the end of the 19th century, some one hundred asteroids were found. The majority of them are circling around the sun in orbits confined between Mars and Jupiter. Some of them, however, are moving along the prolate ellipsoid that intersects the orbit of the earth, producing a non-zero probability of hitting the earth. These asteroids are specifically called Near Earth Asteroids (NEAs). The first NEA was found in 1898.

4-1 Disasters caused by NEA collision

On the morning on 30th of June, 1908, an asteroid with a diameter of 80 m rushed into the Tunguska region in Far East Russia. It exploded several kilometers above the ground, producing a huge hole directly below the explosion and razing all trees and vegetation from an area as wide as 80km×100km. If this scale of disaster took place in densely populated area such as Tokyo, several million or more than tens of millions of people would be killed instantly. The estimated probability of an asteroid hitting any one place on the surface of the earth is approximately once in 1000 years[10].

The collision probability of a larger asteroid is much smaller: once in one million years for an asteroid of 1-km diameter, and once in one hundred million years for an asteroid of 10-km diameter. These probability values, which are fairly reliable, can be calculated using the estimated value for asteroids whose orbits intersect the orbit of the earth.

Figure 8 : Asteroid Distribution in the Solar System: (Inside the orbit of Jupiter)



Many asteroids fly inside the orbit of the earth. The picture shown on upper left of the Chart is an expanded view inside the orbit of Mars, indicating the trajectories of asteroids that come close to the earth.

Source: Provided by the Japan Spaceguard Association

In 1980, Nobel prize laureate Luis Alvalez et al. made their theory public that the sudden, mysterious extinction of the dinosaur around 65,000,000 years ago was due to a collision of a 10-km-diameter asteroid. The crater created by the huge collision, which measures as much as 180km, was discovered in 1991[11].

The extent of the threat presented by the collision of steroids varies considerably, from the devastation of one small country to the destruction of human civilization, or even the annihilation of the human species. Although the probability of any asteroid hitting the earth is extremely low, we must keep in mind that collision will cause calamity beyond imagination.

4-2 NEA observation

(1) Trends in NEA observation

The development of new observation equipment by many astronomers in the 1960s has accelerated NEA research. Today, nearly one million asteroids have been found. Among them, there are nearly 3,000 NEAs.

The U.S.A. is most actively engaged in this field of study. In Japan, the Japan Spaceguard Association[12] (a non-profit organization) is playing a leading role in efforts to detect

Table 2 : Energy Released by Collision of Heavenly Bodies

Magnitude of energy released by collision with various sizes of heavenly bodies		
Asteroid (m)	Comet (m)	Energy released (Equivalent TNT explosive, Megaton)
10	6	0.024
I. Destruction of a nation-sized area		
60	36	20
80	48	50
150	90	340
II. Global destruction		
500	300	13,000
1,000	600	100,000
10,000	6,000	100,000,000
Atomic bomb dropped on Hiroshima		0.02
Nuclear winter		10,000

unknown Near Earth Asteroids[13,14]. If an NEA is found to be on a collision course with the earth, the measures to be taken will be enormous as described in the following section. However, no measure will be taken without steady, painstaking effort to discover and track asteroids that have a non-zero probability of hitting the earth and to calculate their orbits. The trajectories of these asteroids can be calculated with a fair degree of accuracy within the framework of Newtonian dynamics, enabling warnings to be issued at a sufficiently early stage.

(2) Necessity of continuous NEA observation

No NEA should remain undiscovered. Without discovery, there remains a possibility of an unknown asteroid suddenly appearing, causing calamity. To avoid this, a sufficient number of telescopes (several tens of telescopes) dedicated to NEA observation must be properly globally deployed.

By the same token, an NEA, once discovered, must not be lost from our view; the deployment of telescopes to track them constantly is also necessary, enabling regular updates of trajectory information. Currently, this tracking observation depends largely on the volunteer efforts of many amateur astronomers.

As the number of the newly discovered asteroids increases, it is not too early to seriously consider establishing a systematic tracking observation network involving professional astronomers.

4-3 NEA collision prevention

In the unlikely event of an NEA being found on a collision course with the earth, disaster prevention measures must be taken. As summarized in Table 2, the collision will release a much higher order of magnitude of energy (104-108) than the atomic bomb dropped on Hiroshima. There is no way of completely preventing disaster. In fact, very small asteroids with diameters of less than 10m hit the earth at a frequency of roughly once a month. However, these tiny asteroids do not cause major disaster because, thanks to the atmosphere surrounding us, they usually decay their speed before hitting the earth. For larger asteroids (whose diameter is greater than several tens of meters), measures to evade collision must be devised[15].

As mentioned above, the trajectories of asteroids can be fairly accurately calculated using Newtonian dynamics, enabling us to forecast when the collision will take place. Let us assume that the projected collision time, for example, is 30years from now. In this case, if we can modify the speed of the asteroid by 1cm/s to correct its direction now, it will pass by the earth at a distance greater than earth's diameter 30years hence. To give an appropriate pull in the correct direction, the physical parameters of the NEA such as mass distribution, composition, shape (powder or aggregate), must be known, necessitating launching a space probe to gather information. The technology required for NEA exploration is complex, but several countries such as U.S.A. and Japan have already launched space probes as an experimental approach in the vicinity of specified asteroids. Although significant expansion of these projects is required to actually send a space probe to an NEA, it will be well within the reach of our technology. The priority at present is to discover all dangerous asteroids to reduce the probability of unexpected collision even if infinitesimally small[16].

4-4 Observation network required in future

The only one systematic NEA observation effort in Japan is undertaken by the Japan Spaceguard Association using the telescope installed at the Bisei Spaceguard Center. In U.S.A., five groups are actively engaged in NEA observation under the auspices of NASA, and they have already detected more than 600 NEAs with diameters greater than 1km, NASA's primary objective (The total estimated number in this category is between 1,000 and 2,000).

For Japan to make an effective contribution in this area of research, a number of Bisei-type observatories must be added to our arsenal. The steps to be taken for this are as follows:

i) The construction of several optical telescopes whose performance is equal to or better than that installed at the Bisei Spaceguard Center (diameter: 1 m) for the efficient detection of larger NEAs (diameter ≥ 1km). These should be put into operation without delay.

ii) The deployment of a number of smaller telescopes for the continuous tracking of detected NEAs. The number of NEAs whose orbits have been defined is constantly increasing.

iii) The addition of a larger telescope with a greater-than-4-m aperture is highly desirable for probing NEAs with diameters of greater than 100 m.

5 Conclusion

5-1 Crisis management for the human species

We live surrounded by many potential threats including natural disasters such as earthquakes and floods, man-made disasters such as accidents and terrorism, and the food/energy crisis. The first step in crisis management is to be aware that the unthinkable may suddenly happen, destroying the bases of our lives.

(1) Space weather

With the advance of space exploitation and utilization technologies, the fruits of space development (including GPSs, satellite broadcasting, and weather observation) are already ingrained our daily lives. Satellites on their missions are constantly sending meaningful information to the ground. It is therefore essential that we, from the viewpoint of crisis management, consider what will happen if signal waves from satellites suddenly stop arriving. Abrupt changes in space weather can hinder the proper operation of our space equipment; we have had numerous instances of this happen. Continuous, steady effort is required to safeguard the proper operation of these systems, and enhancing these activities will bring us better space weather forecasting, enabling the operators of this space equipment to prepare for disorders more appropriately.

The development and maintenance of various systems are required for more accurate space weather observation (see the main text for details), and national-level engagement and support for this purpose is required.

(2) Space debris

Measures to reduce and remove space debris are essential to maintain the proper operation of existing and future space crafts, and the countries that have launched space crafts should be mainly responsible for performing these activities. As a major space-developing country, Japan should further enhance its role in international cooperation for space debris observation because it has the qualified technologies and facilities to bear this burden.

(3) Near Earth Asteroids

The probability of collision of a Near Earth Asteroid within a few years seems extremely low. Nonetheless, from the viewpoint of crisis management of rare but serious disasters that have hitherto been more or less disregarded, establishing systems for evaluation and early warning systems is essential.

5-2 Systematic support for steady observation research

The effect of fluctuation in the space environment on human activity on the ground is yet to be fully understood. Currently, overall research and operation are split and allocated to a number of research institutes in Japan according to their special interests and strengths, including volunteer efforts.

National Universities sharing this burden need large expenditure for the development and maintenance of equipments, as well as the allocation of researchers and costs for daily observation. These observation efforts have been more or less of a volunteering nature by researchers, and could hinder continuous, systematic research. Conducting daily observation by dedicated personnel should be seriously considered.

Surveying and observing the space environment that surrounds the earth is being conducted through international cooperation. To properly share the burden as a major member of this collective endeavor, establishing a systematic operation system supported by the nation is required, as well as the efforts of first-line researchers.

5-3 Current standing of Japan

Among a number of countries, U.S.A. is head and shoulders above other countries both at the level of technology and the volume of equipments and facilities. Many research efforts now being conducted in Japan are also well acknowledged in the world; these include the Circum-pan Pacific Magnetometer Network (Kyushu University), measures to reduce and protect against space debris, and the operation of a wide-field large telescope (Bisei Spaceguard Center), to name only a few. Unfortunately, the community of those supporting the endeavor is not well known among the general public. Educational campaigns by key figures and proper support for volunteer activities seem effective ways of facilitating the role Japan plays in international collaboration for space environment observation and fluctuation monitoring.

6 Conclusion

Space is connected to life on the earth, and it has much to do with our lives by providing an essential environment. However, it is also important to be aware that space is sometimes dangerous. To conclude, I would like to stress, for the security of human activity on the earth, the importance of supporting research efforts and to raise the interest of the general public, especially the younger generation, to observe and monitor changes in space.

Acknowledgements

For compilation of this article, I am heavily indebted to many people for useful discussion and valuable materials. The space allows me to name only a few, but I am equally grateful to people other than those listed below:

Space Weather: Professor Kiyohumi Yumoto, Head of Space Environment Research Center, Kyushu University

Space Debris: Mr. Tohru Tajima, Associate Senior Engineer, Japan Aerospace Exploration Agency.

Near Earth Asteroids: Dr. Syuzo Isobe, Chairman of the board, Japan Spaceguard Association (NPO); and the people engaged in the operation of the Bisei Spaceguard Center.

Glossary (with full spelling)

- *BAS* British Antarctic Survey
- *CAWSES* Climate and Weather of the Sun-Earth System
- *CME* Coronal Mass Ejection
- *CNES* Center National d'Etudes Spatiales

- •*ESA* European Space Agency
- •*EURECA* European Retrievable Career (European unmanned recoverable free flyer)
- •*FGAN* Forschungsgesellshaft fur Angewandte Naturwissenschaften
- •*GPS* Global Positioning System
- •*IADC* Inter-Agency space Debris Coordination committee
- •*JAXA* Japan Aerospace eXploration Agency
- •*JSF* Japan Space Forum
- •*LDEF* Long Duration Exposure Facility (Equipment for long-term exposure)
- •*MAGDAS* MAGnetic Data Acquisition System
- •*MSD-1* Mission Demonstration test Sattellite-1
- •*NASA* National Aeronautics and Space Administration
- •*NEA* Near Earth Asteroids
- •*NICT* National Institute of Information and Communications Technology
- •*NOAA* National Oceanic and Atmospheric Administration
- •*NPO* NonProfit Organization
- •*NSF* National Science Foundation
- •*PVDF* Polyvinylidene Fluoride (Piezoelectric plastics)
- •*RSA* Russian Space Agency
- •*SCOSTEP* The Scientific Committee On Solar-TErrestrial Physics
- •*SEES* Space Environments Effects System
- •*SFU* Space Free Flyer Unit
- •*SMM* Shuttle Mir Mission
- •*Sq* geomagnetic solar quiet daily variation field
- •*SSN* Space Surveillance Network
- •*TNT* TriNitroToluene
- •*UCLA* University of California, Los Angeles
- •*ULF* Ultra Low Frequency

References

[1] Asahi Shinbun, Sept. 30, 2002 (Evening version) (in Japanese)

[2] NICT (National Institute of Information and Communications Technology) website, (Sun-earth environment information service page): http://hirweb.nict.go.jp/index-j.html

[3] JAXA (Japan Aerospace eXploration Agency) website, SEES (Space Environment Effects System) page: http://sees2.tksc.jaxa.jp/Japanese/index.html

[4] Meteorological Agency Magnetic Observatory website: http://www.kakioka-jma.go.jp/index_j.html

[5] Website for Department of Earth and Planetary Science (Graduate School of Science, The University of Tokyo): http://www.eps.s.u-tokyo.ac.jp/

[6] Website for Solar-Terrestrial Environment Laboratory, Nagoya University: http://shnet1.stelab.nagoya-u.ac.jp/ste-www1/index-j.html

[7] Website for Research Institute for Sustainable Humanosphere, Kyoto University: http://www.rish.kyoto-u.ac.jp/

[8] Website for Space Environment Research Center, Kyushu University: http://www.serc.kyushu-u.ac.jp

[9] “Technical Report on Space Debris,” 1999, Committee on the Peaceful Uses of Outer Space (COPUOS)

[10] Asahi Shinbun editorial, Nov. 24, 1999, “Collision with heavenly objects: crisis management from a human perspective” (in Japanese)

[11] Chuuo-Kouron, 1998, p.216-225, “Menace of asteroid collision” (in Japanese)

[12] Website for Japan Spaceguard Association: http://www.spaceguard.or.jp

[13] Nihon Keizai Shinbun, Jun. 4, 2000, “Guarding the earth from asteroid collision” (in Japanese)

[14] Yomiuri Shinbun, Dec. 14, 2000, “Searching for small asteroids that may in collision course with the earth” (in Japanese)

[15] Asahi Shinbun, Jun.18, 2003, “Preparedness needed for asteroid collision” (in Japanese)

[16] Newton Press, Jul. 1998, “Collision with a asteroid: strategy for avoiding worst-case scenario,” edited by Japan Spaceguard Association (in Japanese)

(Original Japanese version: published in October 2004)