ACTIVE IN-SITU OBSERVATIONS OF SPACE DEBRIS ENVIROMENT IN 800 km ALTITUDE REGIME: A PROPOSAL

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ABSTRACT

Space debris problem now is coming to the time that we cannot ignore it any more. Due to limited capacities and atmosphere disturbances, ground-based facilities generally could only detect space debris larger than 1 cm. In order to detect the remained small ones, this paper proposes an idea of active in-situ observations to investigate space debris environment in the regime of near 800 km altitude, where two recent events dramatically worsened the situation in this regime. Our plan is launching a small satellite whose surfaces are attached with high-performance space debris detectors. When a particle impacts the detector, a pulse signal is generated, detected, sampled, recorded, and further transmitted to the ground, from which we can analyze the impact and estimate the characteristics of the debris, such as mass, size, velocity, direction, etc.

I. INTRODUCTION

Since the launch of the first satellite Sputnik 1 in 1957, human kinds have conducted more than 4,000 space activities. However, along with these remarkable successes, growing concerns about the safety of the on-orbit satellites are also arising, especially caused by space debris. Space debris problem (known as the "Kessler Syndrome") was first recognized by Kessler and Cour-Palais in 1978 [1], and now has been widely aware by international society [2-4]. It states that, when the number of space debris is over a critical spatial density, fragments generated from collisions between existed space debris will cause the total population increasing exponentially in an uncontrollable manner. Now, this problem is coming to the time that we cannot ignore it any more.

Ground-based facilities, such as radars and optical telescopes, are main data acquisition sources for large space debris detection. However, due to limited capacities and atmosphere disturbances, ground-based facilities generally could only detect space debris whose diameter is larger than 1 cm (Fig. 1) [5]. The remained small ones can only be detected by the analysis of retrieved hardware or in-situ observations [6]. Such an example is the Long-Duration Exposure Facility (LDEF), which was launched in April 1984 and left at the 330-480 km altitude for 5.7 years before being retrieved by Space Shuttle Columbia in January 1990 [7]. However, after the end of Space Shuttle program, such operation mode of "launch → exposure → retrieval → analysis" is not possible any more. Therefore, active in-situ measurements/ observations are needed in the future.

This idea is not new. Some active detectors, such as GORID [6, 8] and DEBIE [6, 9], have already successfully realized and obtained fruitful results. However, two recent events dramatically worsened the situation in LEO region and highlighted space debris problem to public. One is the on-orbit breakups of FY-1C satellite on February 11, 2007 [10], and the other is the first accidental hypervelocity collision of two satellites (U.S. Iridium 33 and Russian Cosmos 2251) in history on February 10, 2009 [11]. Fragments generated by these two events quickly doubled the space debris population at the altitude of 600-1000 km. These two landmark events are likely to be the origin of space objects "chain reactions" which was providently predicted by Kessler 30 years ago. Hence, an timely investigation is highly required to evaluate the hazards of these two events.

In this paper, an idea of active in-situ observations is proposed to investigate space debris environment in the regime of near 800 km altitude. First, sources of small space debris are briefly reviewed and the general idea of this proposal is given in Section II and III, respectively. Then in Section IV, some key challenges and main features are discussed, and the requirements of the satellite platform and detectors are discussed in detail. Lastly, this paper is summarized in Section V.

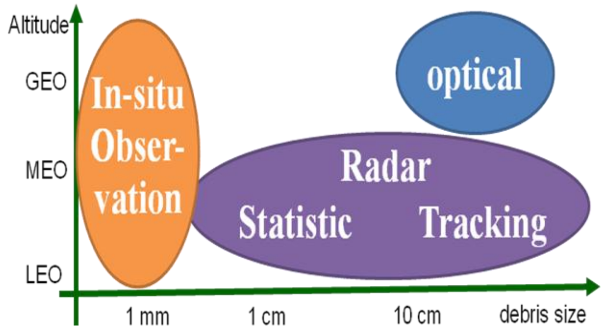

Fig.1 Different observation methods.

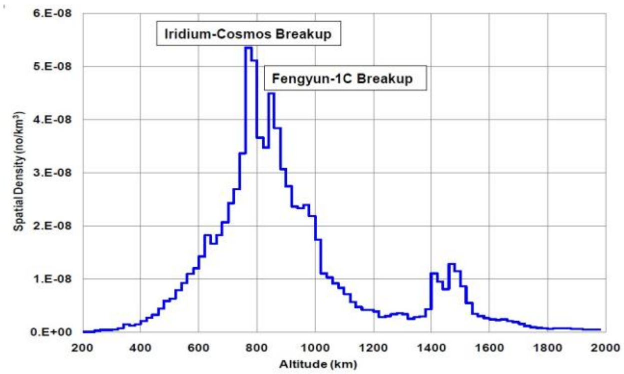

Fig. 2 Spatial density of space debris in LEO, with two peaks near 800 km altitude (Cited from NASA 2011 Report to UNOOSA [12]).

II.SOURCES OF SMALL SPACE DEBRIS

Many space activities have contributed to produce space debris. Here we just keep our focuses on small ones. Sources that generate small space debris are including:

(1) Fragments from on-orbit collisions and breakups. Collisions between on-orbit space objects (satellites or debris), explosions of rocket upper stages with residual fuels and stored energy, and anti-satellite tests during Cold War age have generated large space debris and a huge amount of small ones. For example, the 2009 US/Russia satellites collision has generated ~2000 trackable large fragments, ~100,000 potentially dangerous but untracked mid-sized debris, and ~1,000,000 small ones over 1 mm [13].

(2) Slag. Many small orbital debris particles are created by solid rocket motor (SRM) firings. This type of rocket produces aluminum oxide (Al_2O_3) particles when working. The particles, called slag, are usually larger than 100 um and having considerable contributions to space debris environment [14].

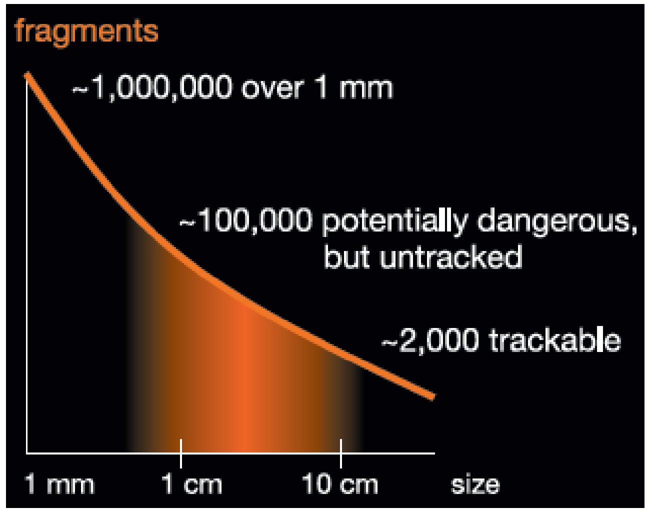

Fig.3 Debris of different sizes from the 2009 US/Russia satellites collision [13].

(3) Sodium-potassium (NaK) droplets. During the 1970s and 80s, the former Soviet Union launched a number of naval surveillance satellites as part of their RORSAT (Radar Ocean Reconnaissance SATellite) program. These satellites were equipped with a BES-5 nuclear reactor in order to provide enough energy to operate their onboard radar systems [15]. Some nuclear reactor cores were ejected from the spacecrafts, which apparently caused a breach in the NaK cooling loop. Today, there may be more than 50,000 NaK droplets larger than 5 mm and much more in smaller diameters in LEO [14].

(4) Micrometeoroids. Micrometeoroids are another kind of small space objects, which are tiny and small particles of rocks in space. They usually have small weights and relative large velocities compared to man-made debris, less than 1 gram and larger than 10 km/s, respectively.

II. PROPOSAL IN DETAIL

In order to investigate space debris environment in the regime of 600-1000 km, our plan is launching a small satellite whose surfaces are attached with high-performance space debris detectors. When a particle impacts the detector surfaces, a signal is generated, detected, sampled and recorded. Then the recording data is further transmitted to the ground via satellite TT&C subsystem. After receiving the raw data, we can further analyze the impact and estimate the characteristics of the debris, such as mass, size, velocity, direction, etc.

The main purposes of this program are:

(1) to investigate space debris environment in the regime of 600-1000 km altitude;
(2) to gather in-situ observation data for space debris modeling;
(3) to better understand the evolution of space debris;

(4) to collect information for spacecraft safety design; and
(5) to provide strong support for future Chinese Space Station program.

By now, the Tsinghua-1 micro-satellite (Fig. 4) is thought to be a good choice of the satellite platform. It has a cuboid body of 330 mm×330 mm×640 mm and advanced integrated design of platform and payloads. This satellite has already completed a successful mission of Earth remote sensing in 2003. On the other hand, active space debris detectors are key components in this program. The potential candidates include detectors based on impact ionization method, detectors made by polarized polyvinylidene fluoride material (PVDF) or by MEMS.

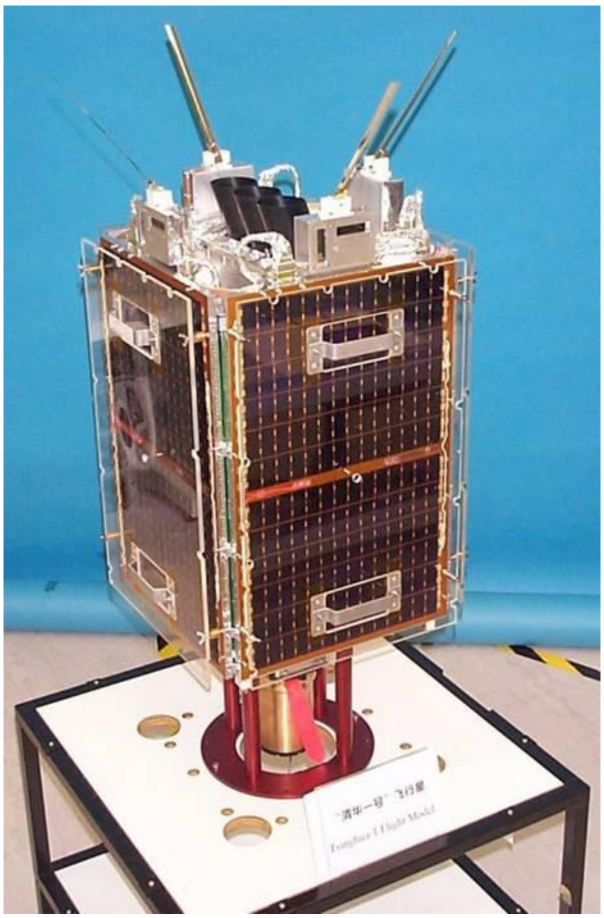

Fig.4 The Tsinghua-1 micro-satellite

III. MAIN FEATURES

In this program, some main features are expected based on state-of-art technologies. The features are summarized in three aspects.

First, the program should have the following general features:

(1) The satellite works in a circular orbit and has a fixed altitude between 600 to 1000 km. (800 km may be a good choice, but the actual parameters of the orbit mainly depend on which launch we can equip.)
(2) The lifetime of this program is expected to longer than 10 years.
(3) This program can detect the debris size from 10 micrometer to 1 millimeter.
(4) Impact data is detected, sampled, recorded, and transmitted to the ground when the satellite flies over the tracking station.

Second, the satellite platform should have the following features:

(1) The satellite should have enough surfaces to place the detectors and the total weight should be as low as possible.
(2) The communication subsystem has enough ability to transmit the recorded data to the ground. In this program, there would be only very little quantity of data.

Third, since the detectors are the key components of this program, they should have the following features:

(1) It should have the ability to detect the impact smaller than 10 um and have a longer lifetime than the program required.
(2) It can distinguish two consecutive impacts whose time interval is longer than 10 s.
(3) It has the ability to suffer the impact of space objects whose sizes are larger than 1 cm.

IV. CONCLUSIONS

Space debris problem now is coming to the time that we cannot ignore it any more. Due to limited capacities and atmosphere disturbances, ground-based facilities generally could only detect space debris larger than 1 cm. In order to detect space debris smaller than 1 cm, this paper proposes an idea of active in-situ observations to investigate space debris environment in the regime of near 800 km altitude. Our plan is launching a small satellite whose surfaces are attached with high-performance space debris detectors.

We expect that this program can obtain fruitful data about space debris environment near 800 km altitude, and also keep a monitor on its evolution in the following years. The observation data is expected to play an important role to update space debris models at this altitude.

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