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Leonid Meteor Observer in LEO: A University Microsatellite to Observe a Meteor Shower From Space

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Abstract

This paper presents university-based design and development of a micro-satellite for the observation of a meteor shower from the low Earth orbit. The satellite will be launched as a piggy-back payload of a commercial rocket launcher, a few weeks before the 2001 or 2002 Leonid meteor maximum in which thousands of meteors are scientifically expected. The goal of the mission is to conduct the scientific observation of the prospective meteor outburst from out of atmosphere, counting the meteors in the large coverage of the night sky looked down on Earth and obtaining visible-Ultra Violet spectrographs of the meteor. Possible launch opportunity remains to be seen, but the designs of the satellite bus and scientific payloads are now initiated.

1. Introduction

An international team led by Tohoku University, Japan is now putting the students' effort into a university student-built, micro-satellite for the observation of a meteor shower from the low Earth orbit. The satellite will be small enough to be launched as a piggy-back payload of a commercial rocket launcher, a few weeks before the 2001 or 2002 Leonid meteor maximum in which thousands of meteors are scientifically expected.

The goal of the mission is to conduct the scientific observation of the prospective meteor outburst from out of atmosphere, counting the meteors in the large coverage of the night sky looked down on Earth and obtaining visible-Ultra Violet images and spectrographs of the meteors, which are difficult from the bottom of the atmosphere. From the engineering point of view, the hazard on a satellite in an intensive meteoroid stream may be also estimated. More interestingly a spectacular view of the "downstream" shower, which never seen from the ground, can be photographed (Fig.1).

The satellite will be built by international university students in a suitable fashion for a piggy-back launch, cost effective and quick development, to maximize scientific and educational objectives. The University Space Systems Symposium, which already started high activities of CanSat and CubeSat, supports organizing a team effort between the USA and Japan.

This paper is organized in the following way: Section 2 summarizes the mission outline. The scientific background and advantages of meteor observation from space are briefly touched in Section 3. Current phase A design of the satellite is introduced in Section 4. The past and future milestones of the mission are reviewed and discussed in sections 5 and 6.

Figure 1: Artist impression of how the Leonids outburst looks from space

Figure 2: One-minute composite image of the 1999 Leonid meteor shower peak (< 5th mag.) over Europe, imaged with the HDTV-II in 59 x 33 degrees FOV developed by NHK (from Yano et al., [2]; Courtesy: NHK and H. Yano)

2. Mission Outline

The goal of the proposing mission is to make scientific observation of the meteor shower at the expected time and date for Leonids maximum.

Meteor shower is phenomenon that a stream of interplanetary dust enter and ablate in the atmosphere. The dust stream is originated by a so-called parent comet, and due to the orbital geometry, the shower from a specific parent comet occurs on a very specific day.

The Leonids is one of such meteor showers but it attracts special attention by dramatic outbursts in history, which happens almost every 33 years synchronizing the encounter with the parent comet, named P/Tempel-Tuttle. But, it has been difficult to predict exact date and time of the outburst till very recently. However, the latest model successfully predicted the 1999 outburst with several thousands of meteors per hour, and it tells further outburst will happen at around 18:19 UT Nov. 18, 2001 and 10:36 UT Nov.19, 2002 [1].

Another difficulty in observing the meteor is weather condition and light pollution. In order to get rid of these disturbances, the airborne observation campaign was carried out by NASA in 1998 and 1999 (Fig.2)[2], which helped greatly to improve the meteor science and outburst prediction.

Even flying high in the sky, say 10km altitude, the observation has to be made through the dense of the atmosphere, which brings disadvantage in the ultra-violet (UV) wavelength. If the observation is made from the low Earth orbit, looking down from out of the atmosphere over the night sky, it will be certainly the scientific advantage to investigate the meteor glow at high altitude in the near UV wavelength.

The proposing mission is thereby summarized as follows:

- Make scientific observation of the prospective Leonids meteor outburst, in 2001 or 2002, from low Earth orbits.
- The UV photometry and spectrographs are prime payloads of the mission.
- The satellite can be simplified as long as the scientific goals are achieved.
- So far, no spaceflight mission is planned for the forthcoming Leonids outburst by space agencies in the world, and the preparation time is not left much. A rapid, simple, and cost-effective design and development are strongly required.
- The satellite can be as small as for the piggy back launch by a commercial rocket vehicle.
- The outburst lasts for only a few hours, so if the launching schedule is controlled, the life time of the satellite can be minimized. However, due to the nature of the piggy back launch, the schedule is subject to the main payload. The satellite then should be designed durable for several months of waiting in orbit. Anyway, the satellite must be launched before the day of the outburst.

3. The Science

3.1. The Leonid Maximum Opportunity

While typical sporadic meteors start to illuminate at 80-90 km altitude, many of the Leonid maximum components were found to have started at as much higher altitudes as > 150 km to even about 200 km [3]. This is because the meteor particles of Leonids have higher encounter velocity at 72 km/s than the particles of other meteor groups or sporadic ones. Such high altitude about 200 km is usually considered "space" with extremely tenuous atomic atmosphere, but the materials and the mechanisms of the illumination are not solved yet. It can be assumed that there must be organics and volatile materials with low sublimation temperature. In fact, the analysis on the recent Leonid airborne observation suggests that there are many organic features, which are particularly found in the near UV spectrographs [4]. Organic materials, if exist, have close relation with the seeds of life.

The Leonid maximums are very unique and important opportunity to investigate the existence and composition of organic materials in the outer atmosphere region. It is thereby strongly suggested that the space borne observation with spectrography should be prepared. Note again that the space borne observation is most effective with Leonids, because such intense meteor encounter and high altitude illumination are very unlike in other meteors.

3.2. Advantage of the Orbital Observation

(1) The observation of meteors is, like other astronomical events, strongly affected by the condition of the sky, including weather, air and light pollution, and the moon phase. Orbital observation can eliminate these disturbances.

As for the moon phase is considered, the 2001 maximum is around new moon, but the 2002 is nearly full moon. This is the worst condition for the ground observation, yet moon light scattering will not be so bad for the observation of the high altitude meteors from the low Earth orbit.

(2) If focusing at the high altitude meteors around 200 km, from a 300 km low Earth orbit is closer than from the ground.

(3) While ground human-eye observation generally covers 120 degree solid angle at 100km altitude, the space borne observation can expect far wider coverage of the sky by using the Earth itself as a dust detector. This is advantageous in obtaining the flux statistics.

(4) If the attitude of the observation satellite is stabilized, the observation of "stationary meteors" is easy by looking at the Earth pointing direction, the convergence, opposite to the radiant. This is particularly advantageous in setting the spectrometer.

(5) Trajectory determination of a meteor is possible with respect to background city lights, compared to background stars.

(6) Ninety minutes of orbital period guarantees to experience a portion of short-lived peak (e.g., 2 hours in 1999.)

4. Satellite Design

In order to provide the scientific observation discussed in the previous section, the design of the satellite is illustrated here. Noting that the developing time is not much left for the forthcoming outbursts, the design must take off-the-shelf technology and components as much as possible. And the size and weight should be small enough for potential piggy-back launch. As the launch vehicle is not fixed yet, the design illustrated in Figure 3 represents one of possible options. The design is flexible to meet the interface requirement of a launch vehicle.

Mission payloads Mission payloads includes at least (1) wide angle camera and (2) spectrometer, both should be mounted to look down the Earth. The wide angle camera ideally covers the whole globe with visible wavelength, but the sensitivity should be extended to near UV region. The spectrometer is tuned to cover the specific peaks of interests in near UV wavelength. The weight of mission payloads is estimated 5 to 10 kg altogether. If the situation allows, the HDTV technology is to be applied that dramatically improve the pixel resolution and the light sensitivity.

Orbit A circular low Earth orbit around 300km altitude is most preferable. There is any special requirement in the orbital inclination, but around 35-40 degrees are preferable so that the ground trace covers major cities in the world.

Attitude Stabilization Attitude should be stabilized with enough precision for photographing. High precision is not necessary. Off-the-shelf technology of 3 axis stabilization for small satellites with reaction wheels and magnet torquers will be applicable. A simplest option may be graity gradient stabilization with the increased damping by magnet torquers.

Global Positioning Global positioning information will be important for scientific data analysis, to determine the meteor trajectory for example. But again, extremely high precision is not necessary.

Communication and Data Handling VHF uplink at 9.6 kbps and S-band downlink around 38 to 96 kbps will be possible range. Since the photographing is the mission focus, the downlink with much higher bit rate is ideal. If the satellite has enough memory space to store the images, lower down link bit rate can work.

If each image has 100k byte (which is big enough for a JPEG picture on a PC) and the communication allows 96 kbps downlink, the satellite can send (broadcast) one image in every 10 seconds. Those images can be received by collaborators and armature volunteers spread out over the world. Armature networks for the meteor observation may be helpful to organize a campaign, which should be good in attracting public attention and reducing the cost to hire professional stations.

Physical Dimension Physical dimension of the satellite can be around 500 mm cube or less, and the weight may be in the range of 5 to 20 kg.

Power If the satellite dimension is 500 mm cube, each surface will generate around 30W of electricity assuming that the surface is covered by conventional solar cells. A secondary battery is needed for the cycle to charge in a day side and to do the mission in a night side. The selection and sizing of the battery must be done to meet the power consumption of the mission instruments.

Mission Life and Launch Date If the launch date of the satellite can be controlled, the mission life is less than a week. But due to the nature of a piggy-back launch, the launching date is subject to the host. The satellite therefore should be designed to meet around 1-6 months launch in prior to the mission date.

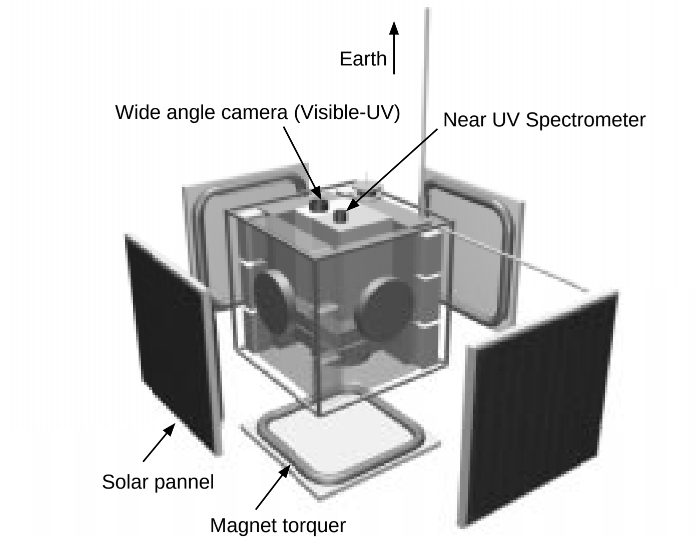

Figure 3: Illustrative design of the Leonids Meteor Observer

5. Background Milestones

5.1. The Satellite Design Contest, Japan

Since 1993, The Satellite Design Contest has been held in Japan to encourage design capability and fresh ideas of space systems from students in universities, colleges and high schools. The contest is co-sponsored by National Space Development Agency of Japan, Institute of Space and Astronautical Science (two space agencies) and The Japan Society of Mechanical Engineers, The Japan Society for Aeronautical and Space Sciences, The Institute of Electronics, Information and Communication Engineers (three academic societies) and Japan Space Forum (an organizer). Each year almost 20 to 30 proposals in total are submitted for two categories, System Design and Novel Idea, and about 5 for each are selected for a final presentation. The first prize is given to the best proposal from each category. The judges include managers of space agencies, university professors, engineers from satellite industry, and sometimes a journalist.

The mission proposal of Leonids Meteor Observer was submitted to the 7th Satellite Design Contest, 1999, by Mr. Hiroshi HAMANO and Ms.

Satoko ABIKO, undergraduate students of Tohoku University, and received the First Prize in the idea category [5].

5.2. University Space System Symposium

Since 1998 the University Space System Symposium is organized in order to investigate opportunities of collaboration between US and Japanese academic institutions, in the area of design and development of satellites and related high-tech machines. From Japan, five universities in 1998 and seven in 1999 participated in the symposium, those of whom are very active and enthusiastic in the Satellite Design Contest. The mission proposal of Leonids Meteor Observer was presented at the USSS'99, and received strong attention from the participants. In the group discussions by students and instructors, a initiative framework was formulated between Santa Clara University, U.S.A. and Tohoku University, Japan, to jointly investigate the possibility to develop and launch the satellite.

6. Future Milestones

Several future milestones are currently planned in order to achieve the stated mission goals.

Scientifically, continued effort will be made to refine the estimates of maximum Leonid shower activity and to develop the sensitivity of the science instrumentation in order to maximize science return. In addition, the mission team is exploring a collaborative ground-based observing system using a network of globally distributed sky cameras controlled through the Internet.

Technically, design and development of the satellite bus and the mission control architecture have commenced. Tohoku University is currently engaged in subsystem-level trade-off analyses and will soon begin component-level development and prototyping. Santa Clara University is developing the mission control architecture which will consist of a professional-grade mission control complex with several distributed communications stations; funding for this portion of the system has been acquired.

Programmatically, the international team must secure adequate funding, identify a suitable launch opportunity, and resolve technology transfer issues that prohibit joint satellite development or delivery of satellite technology from U.S. participants to Japanese participants. If restrictions continue to exist, the international team will attempt to comply with U.S. law through a division of labor at the space/ground segment level; in this case, Tohoku University will be completely responsible for payload and satellite development while Santa Clara University will provide operational ground control of the mission. Alternatively, a U.S. university registered with the U.S. government for technology transfer capability may join the team in order to resolve the necessary disclosure and oversight requirements.

7. Conclusion

In this paper, we proposed a microsatellite mission for the observation of the expected Leonids meteor maximum from the low Earth orbit. The satellite will be designed and developed in the fashion of rapid and cost effective prototyping approach, to see a timely piggy-back launch for this unique scientific phenomenon.

The mission has strong potential to bring substantial return to meteor-planetary science and thereby establish a remarkable example that a university-made small satellite could contribute to cutting-edge science.

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