# RECENT ACTIVITIES AND FUTURE DIRECTION OF JAPANESE SOUNDING ROCKET EXPERIMENTS FOR SCIENTIFIC PURPOSE

**Takumi Abe, Masato Nakamura, Nobuaki Ishii, and Yoshifumi Inatani**

*Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency*
*3-1-1, Yoshinodai, Sagamihara 229-8510, Japan, E-mail: abe.takumi@jaxa.jp*

## ABSTRACT

Sounding rocket experiments have been successively conducted for more than 40 years in Japan. These include various scientific and engineering topics. In this paper, we present recent activities of Japanese sounding rocket experiments for the last two years (2007-2008 fiscal year) and also describe a future direction on the experiment in the mid-term range.

## 1. INTRODUCTION

The Institute of Space and Astronautical Science (ISAS) of Japan Aerospace Exploration Agency (JAXA) has continuously launched sounding rockets for more than 40 years. The primary purpose of these rocket experiments includes various topics; physics of upper atmosphere (mesosphere, thermosphere, and ionosphere), magnetospheric physics, astrophysics, instrumental demonstration and engineering. Among them, the lower ionospheric physics is one of the important scientific subjects that have been investigated most effectively by this space-platform. In this paper, we present the recent activities for the last two years.

## 2. SOUNDING ROCKETS IN OPERATION AT JAXA

ISAS of JAXA is now operating three different types of the sounding rockets; S-310, S-520, and SS-520. The smallest rocket, S-310, can reach up to 200 km with a maximum weight of 50 kg payload, while S-520 goes up to 300 km altitude. Other specifications are described in Tab. 1. In the recent years, two sounding rockets are launched every year; one in summer and the other in winter.

*Table 1. Sounding rockets of JAXA*

| Rocket type | S-310 | S-520 | SS-520 |
|---|---|---|---|
| Length (m) | 7.1 | 8.6 | 9.65 |
| Diameter (mm) | 310 | 520 | 520 |
| Weight (ton) | 0.7 | 2.2 | 2.6 |
| Max. altitude (km) | 210 | 270-350 | 1000 |
| Science payload (kg) | 50 | 95-150 | 140 |

## 3. RECENT ACTIVITIES OF SOUNDING ROCKET EXPERIMENTS

A total of 4 sounding rocket experiments were conducted for the last two years; S-520-23 in summer of 2007, S-310-38 and S-520-24 in 2008, S-310-39 in winter of 2009. In this paper, we briefly introduce summary of each experiment as well as main results.

### 3.1. S-520-23 experiment

Neutral atmosphere strongly controls both dynamics and thermodynamics of the ionosphere, because the ionization rate is less than 1 % in the lower ionosphere. The external force by neutral atmosphere is dominant in the plasma dynamics of low and mid latitude ionosphere. Among the coupling processes between neutral atmosphere and plasma, the ionospheric dynamo is an important process for the generation of large scale structure of the ionosphere, such as equatorial plasma density variations and temperature anomaly. On the other hand, small scale structure such as traveling ionospheric disturbances (TID) associated with atmospheric gravity waves are also affected by the coupling between neutral atmosphere and plasma. The plasma density fluctuations generated by the atmospheric gravity waves are amplified by electromagnetic instabilities. The growth of some of these instabilities may be highly dependent on the neutral winds. However, we do not yet understand in detail most of these processes, because the neutral winds in the thermosphere are very difficult to measure and hence have not been measured accurately.

*Table 2. Instruments onboard S-520-23*

| Instrument | Measurement item |
|---|---|
| Lithium ejection system | Neutral wind |
| Suprathermal ion imager | Ion drift |
| Electric field & MF wave receiver | E field & Wave (DC-32 Hz) |
| Magnetometer | Magnetic field |
| Langmuir probe | $T_e$ and $N_e$ |
| Plasma diagnostic probe | $N_e$ perturbation |
| Impedance probe | $N_e$ |
| Beacon transmitter | Total electron content |
| Multi spectra imager | Imaging of cloud |
| Sun sensor | Sun angle |

In September 2007, we conducted WIND (Wind measurement for Ionized and Neutral atmospheric Dynamics study) campaign by using "S-520-23" rocket in Uchinoura, which is located in the southern part of Japan, to investigate coupling processes between neutral atmosphere and plasma in the lower thermosphere and ionosphere. The momentum transfer is a key of physical

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process, such as the interaction between neutral atmosphere and plasma associated with a medium scale traveling ionospheric disturbance (MS-TID) occurring in the mid-latitude lower thermosphere and ionosphere. A total of 10 scientific instruments were installed on the rocket to make a comprehensive measurement of neutral and charged particles in the lower ionosphere. A complete list of the instruments is given in Tab. 2.

In this experiment, we tried to release Lithium vapor at three different altitudes from the rocket during its flight. The Lithium is supposed to have emission due to a resonant scattering by sunlight, and it is possible to estimate the neutral wind by tracking its temporal movement. Fig. 1 shows an image of Lithium emission taken from Uchinoura station. Vertical profile of the neutral wind was derived from the time variation of the Lithium images [1]. The information on the neutral wind will be compared with the ion drift derived from the Suprathermal Ion Imager observations.

*Figure 1. Image of Lithium emission (Photo credit: Hokkaido Univ. and Kochi Univ. of Technology)*

### 3.2. S-310-38 experiment

In February, 2008, we conducted S-310-38 rocket experiment, whose scientific objective is to make a comprehensive observation of the ionospheric plasma density structure from various angles by using three different measurement techniques; optical, radio-wave, and in-situ probe. A main target of this campaign was non-uniform plasma density structure such as the sporadic E layer in the lower ionosphere. The main instruments onboard were 1) a receiver for MF and VLF wave to estimate the electron density distribution along the ray path, 2) $Mg^+$ ion imager to observe its horizontal distribution, and 3) Impedance probe and Langmuir probe to measure the local electron density. A complete list of the instruments is given in Table 3.

The Mg+ ion imager [2] is a filtered multi-anode photometer which has an eight-channel linear array photo-multiplier tube as a detector. The interference filter has a center wavelength of 278.4 nm and a bandwidth (FWHM) of 16.3 nm. The instantaneous field of view is 1°×1.25° for each channel and 1°×10° for a total of eight channels. The line-of-sight is tilted at 150° with respect to the rocket spin axis. Using the rocket spin, this imager can scan a doughnut-shaped region with a width of 10° rearward from the rocket.

*Table 3. Instruments onboard S-310-38*

| Instrument | Measurement item |
|---|---|
| MF & VLF Receiver | Electron density profile |
| $Mg^+$ Ion Imager | $Mg^+$ ion distribution |
| Magnetometer | Magnetic field |
| Langmuir Probe | $T_e$ and $N_e$ |
| Impedance Probe | $N_e$ |
| Chaff | Neutral wind |
| Imaging Attitude Finder | Rocket attitude |

The S-310-38 rocket was launched from Uchinoura at 18:14:40 JST on February 6, 2008, and all the onboard instruments successfully performed their measurements as planned. The altitude profile of the electron density derived from the impedance probe measurements showed that the *Es* layer was located at an altitude of 100 km during both the ascent and descent of the flight. Simultaneous observation with a ground-based ionosonde at Yamagawa identified a possible existence of the *Es* layer at almost the same altitude. The $Mg^+$ ion imager successfully scanned the horizontal $Mg^+$ density perturbations in the vicinity of *Es* layer and found they had patch-like and front-like structures [2].

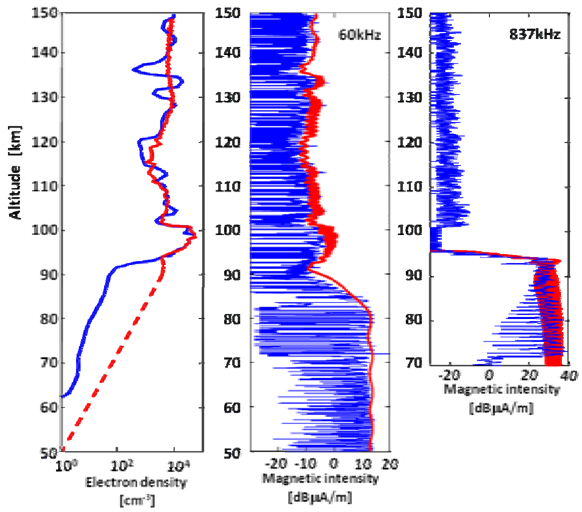


*Figure 2. From the left, electron density profile from the wave receiver (blue line) and impedance probe (red curve), magnetic intensity at 60 kHz and 837 kHz frequencies observed on the rocket.*

In the wave measurement, the receiver detects the magnetic intensity at 60 kHz (VLF) and 873 kHz (MF) frequencies, which is greatly affected by the electron density distribution along the ray path. The 60 kHz wave is transformed in its mode after entering into the ionosphere, and propagates in the whistler mode above the altitude for the total reflection. From the altitudinal variation of the intensity, it is possible to estimate the altitude profile of electron density. Left panel of Fig. 2 shows altitude profiles from the wave receiver at 60 kHz and 837 kHz and the impedance probe on the rocket, and centre and right panels represent the magnetic intensity of the wave at these frequencies.

The overall trends of electron density from the two measurements almost agree each other. However, the density profile from the wave measurement is more structured. Using altitudinal variations of magnetic intensity below 90 km altitude, it is possible to estimate the electron density profiles in the altitudes between 70 and 90 km, while no reliable measurements can be made by *in-situ* probes.

### 3.3. S-520-24 experiment

In August 2008, ISAS of JAXA conducted micro-gravity experiment using S-520-24 rocket. The objectives of this rocket experiment were (1) to observe faceted crystal growth (FCT) and (2) to observe diamond synthesis from a gas phase (DIA) on the microgravity condition during the flight. The rocket reached an altitude of 293 km at 274 sec after the launch, and all the experiments were successfully conducted during 7-min microgravity condition.

In the FCT experiment, morphological change of a growing crystal surface and temperature distribution in undercooled melt were simultaneously measured in purified phenyl salicylate by a microscopic interferometer. It provides basic data for a crystal growth experiment under a long-duration microgravity, which is now being conducted on Japanese experiment module of ISS in 2009. In the DIA experiment, Diamond was synthesized in hydrogen gas on a silicon substrate. Some gas species were activated at 2000˚C by the Joule heating of a carbon rod during the process. Active species Hβ and Hγ, which were difficult to measure on the ground due to the strong thermal convection, were confirmed by the onboard spectrometer.

### 3.4. S-310-39 Experiment

The large-scale circulation in the high latitude thermosphere has been investigated with many modeling studies and from satellite observations. Compared to the large-scale circulation, meso-scale (1-1000 km) phenomena such as the thermospheric response to auroral disturbances are not well understood. Recent rocket observations in the high latitude thermosphere are weighted in wind measurements, and thereby strong winds and wind shears are observed in the lower thermosphere. However, a cause of these vertical wind structures is not fully identified mainly because of uncertainty in parameters necessary for the modeling study. One of the key parameters to facilitate studies on the dynamics and energetics in the lower thermosphere is neutral atmospheric temperature, which is important to understand thermal structure and the auroral heating.

In order to investigate the dynamics and energetics in the polar lower thermosphere, coordinated sounding rocket observation with the European Incoherent Scatter (EISCAT) radar and ground-based Fabry-Perot Interferometers (FPIs) was successfully conducted during the Dynamics and Energetics of the Lower Thermosphere in Aurora (DELTA) campaign on 13 December 2004. In the DELTA campaign, the vertical profile of neutral temperature in the lower thermosphere was obtained by the sounding rocket experiment, the time variations of neutral temperature and winds at the auroral emission altitudes were measured with two FPIs, and the vertical and temporal profiles of ionospheric parameters and neutral winds were observed by the EISCAT radar.

While the campaign provided information on upward vertical wind up to 40m/s at an altitude of 120 km associated with the strong Joule and particle heating event, vertical profile and horizontal distribution of this upwelling is still unknown. It is noticeable that the DELTA campaign has given a comprehensive description of the dynamics and energetics of the polar lower thermosphere. On the other hand, neutral wind information that includes vertical and horizontal profiles with high spatial resolution should be indispensably discussed with the temperature profile for a better understanding of the spatial structure and source mechanism of such large vertical wind events.

Based on the success of the DELTA campaign in 2004, the DELTA-2 campaign was conducted in January 2009. Main objective of this campaign is to further elucidate the atmospheric dynamics and energetics in the polar lower thermosphere, and in particular the local neutral wind field structure associated with auroral energy inputs was focused. In the DELTA-2 campaign, a Japanese sounding rocket released Trimethyl Aluminum (TMA) along the rocket trajectory and then high-resolution neutral winds can be derived from the TMA trails by observing with ground-based cameras at the remote sites. By releasing the TMA puffs intermittently with a solenoid valve, it is possible to measure not only horizontal winds but also vertical winds.

The S-310-39 rocket was launched from Andøya Rocket Range at 0:15 UT on January 26, 2009. It is very fortunate that the aurora breakup has started at 0:25 UT when the TMA trails still remained in the field of view of the ground-based cameras. This campaign provided a unique data set which enables us to investigate an evolution of the wind structure during the geomagnetically active period. On the other hand, it is unfortunate that no neutral temperature measurements could be made due to malfunction of the rocket-borne instrument. During the campaign, many ground-based instruments such as the EISCAT radar, FPIs, all-sky cameras, and magnetometers successfully performed their measurements, which are also intrinsic for understanding of the thermospheric response to auroral energy inputs.

## 4. FUTURE DIRECTION

Until now, we have conducted rocket experiments so that one scientific objective can be achieved by one launch. In the years ahead, we will make a more strategic plan with a mid-term (~5 years) subject which should be performed by a series of experiments, recognizing a distinctive feature of the sounding rocket for upper atmospheric and ionospheric studies.

We have to keep the three important roles of the sounding rocket in mind, when thinking of the future plan. First, it should be used for further understanding of the upper atmosphere, thermosphere, and ionosphere, because it is the most effective tool for direct observation of these regions. It will have synergy effect of the research progress on understanding of the related fields such as planetology, meteorology, environmental science, and plasma physics. Also, it provides high-altitude platform for continuous monitoring of Earth's atmospheric environment. Another important role is that the sounding rocket can provide a good opportunity in a shorter term to demonstrate satellite-borne instruments, because it can give easier access to people compared to satellite project in terms of time and cost.

We have started discussion on the future plan in the mid-term range. For the sounding rocket program, an improvement of the onboard instruments in terms of accuracy and function will be key issue for the next five years. Close coordination between direct and indirect measurements is also important to facilitate our understanding. In the next term, we'd like to further spread our sounding rocket into various regions such as higher and lower latitude. Thus, the global deployment will be essential. Our institute is now developing reusable sounding rocket, by which we can control its trajectory. Then, we will be able to observe phenomena from various angles and in a larger time scale. It will become possible to differentiate the temporal and spatial variation. Around that time, the satellite to observe the upper atmosphere by remote-sensing technique will be in orbit, and then a combination between the macro-scale observation by satellite and micro-scale observation by the sounding rocket will be very promising.

## 5. REFERENCES


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