Auroral Sounding Rocket Experiment of the 26th Japanese Antarctic Research Expedition: Mission Plan

Hisao YAMAGISHI* and Hiroshi FUKUNISHI*

第26次南極地域観測隊で打ち上げるオーロラ探査ロケット：観測計画

山岸久雄*・福西　浩*

要旨：第26次南極地域観測隊越冬隊では国際中層大気観測計画 (MAP) に呼応して，1985年の冬季に2機のオーロラ探査ロケットを打ち上げる計画である．この観測はオーロラ発光高度での波動-粒子相互作用の過程を明らかにすることを目的としている．この論文では観測計画の概要を述べる．

Abstract: It is scheduled that two sounding rockets are launched from Syowa Station, Antarctica in the austral winter of 1985 as part of the international Middle Atmosphere Program (MAP), by the wintering party of the 26th Japanese Antarctic Research Expedition. This experiment aims at the study of the wave-particle interaction processes on auroral field lines. The present paper gives an outline of the mission plan of the experiment.

1. Introduction

The scientific aim of the international Middle Atmosphere Program (MAP) scheduled for 1982–1985 is to obtain a comprehensive understanding of the middle atmosphere which is defined between the tropopause and the lower thermosphere (approximately 10–120 km). Our knowledge of the middle atmosphere particularly in the southern polar region has been most deficient. Therefore, the Geodesy Council of Japan presented a recommendation to the Ministry of Education, Science and Culture that coordinated observations of the middle atmosphere should be carried out at Syowa Station in Antarctica as one of the major national MAP projects. Under these circumstances the National Institute of Polar Research has organized the Antarctic Middle Atmosphere Project for 1982–1985. The project comprises observations of the middle atmosphere by means of remote sensing techniques from the ground, aircraft and spacecraft and *in situ* measurements aboard aircraft, balloons and rockets (FUKUNISHI *et al.*, 1984).

The major subjects of the rocket experiment are the study of the auroral energy which plays an essential role in energetics and dynamics of the polar middle atmosphere and the study of the vertical profiles of wind and temperature. The 26th Japanese Antarctic Research Expedition (JARE-26) party will launch in 1985 two S-310JA-type rockets for the former study and eleven MT-135JA-type meteorological rockets for the latter study. The mission plans of these rocket experiments have been approved in February 1984 by the Committee on Upper Atmosphere Physics in the National In-

* 国立極地研究所. National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173.

stitute of Polar Research. This paper gives the outline of the mission plan of the S-310JA rocket experiment.

2. Scientific Aim

The scientific aim of this rocket experiment is to study wave-particle interaction processes in auroras. Measurements of auroral electrons by a number of sounding rockets and satellites have revealed that the energy spectra of auroral electrons observed in the vicinity of auroral arcs show a predominant peak at several keV (*e.g.*, ARNOLDY, 1981). This component makes a large contribution to optical emissions of auroras. It has been suggested that such peaks are formed by a field-aligned potential difference at the altitude of 1Re (*e.g.*, KAN and LEE, 1981). The results of the recent rocket observations, however, are inconsistent with the acceleration process due to field-aligned potential difference. WHALEN and DALY (1979) showed that the pitch angle distribution of precipitating electrons is field-aligned near the edges of auroral arcs, while it is isotropic at the center of arcs, and that field-aligned electron precipitation is observed over a wide energy range from 0.5 to 60 keV. There is evidence further that energy spectra of precipitating electrons often have two peaks (ARNOLDY *et al.*, 1974; HOFFMAN and LIN, 1981).

These results suggest that precipitating electrons are accelerated again by plasma waves at low altitudes less than 1 000 km. GOUGH and URBAN (1983) have given strong evidence on the low-altitude acceleration. They observed from the rocket experiment that the flux of precipitating electrons, which show a large peak at 5 keV, is modulated by 30% at its peak energy. They have interpreted that precipitating electrons are accelerated and scattered by electrostatic electron cyclotron waves at an altitude where $f_{UHR} \cong 2f_{ce}$ (approximately 500 km). Here f_{UHR} and f_{ce} are upper hybrid frequency and electron gyrofrequency, respectively. This interpretation has not been confirmed so far because simultaneous observations of plasma waves in the HF range and associated flux modulation of precipitating electrons have never been conducted. However, the rocket experiment carried out at Syowa Station during the IMS period suggests that the interaction between auroral electrons and electrostatic plasma waves in the HF range (approximately 2–4 MHz) is occurring since intense emissions were observed in the frequency range between f_{UHR} and the cut-off frequency of Z-mode wave (MIYAOKA and OYA, 1984).

It is also predicted that auroral electrons are accelerated by electrostatic waves in the ELF-VLF range such as LHR mode waves and electrostatic ion cyclotron waves since these kinds of waves were measured in auroras by sounding rockets (YAMAGISHI *et al.*, 1981; KOSKINEN *et al.*, 1983).

The electrostatic waves mentioned above are essential for the acceleration of precipitating electrons at the rocket altitude since the resonant interactions between waves and electrons occur over a wide energy range of electrons. In contrast, electromagnetic mode waves such as auroral hiss and auroral kilometric radiation (AKR) are excited at altitudes of several thousand kilometers on auroral field lines through wave-particle interaction processes. It is well-known that auroral hiss emissions propagate as whistler mode waves toward the ground. It is also suggested that downward auroral kilometric radiations are converted into whistler mode waves and then they are observed at the rocket altitude (MIYAOKA and OYA, 1984). Therefore, rocket observations of auroral hiss and AKR and associated precipitating electrons are essential for the study of generation and propagation mechanisms of these waves.

The electron density irregularity in the E region suggests another interesting wave-particle interaction process. Although it is suggested that ion acoustic waves excited by the cross-field instability or the two-stream instability cause fluctuations of electron density (OGAWA *et al.*, 1976), simultaneous measurements of various kinds of parameters such as magnetic and electric fields, plasma waves, precipitating electrons and electron density fluctuations have not been carried out. Flickering of auroral luminosity at the frequency of 5–15 Hz is also one of the important wave-particle interaction processes associated with auroral arcs.

As mentioned above, various kinds of wave-particle interaction processes are occurring in auroras. The S-310JA-11 rocket experiment aims at the understanding of the wave-particle interaction processes associated with auroral arcs. The major scientific aims are summarized in Table 1. On the other hand, the S-310JA-12 rocket experiment aims at the study of the wave-particle interaction processes in pulsating auroras. Simultaneous measurements of waves and particles in pulsating auroras are particularly interesting since we have no information as to the modes of plasma waves

Table 1. Scientific aims of the S-310JA-11 rocket experiment. The rocket will be launched into active auroral arcs.

<table>
<tr><th colspan="2">Scientific aim</th><th>In situ measurement on board the S-310JA-12 rocket</th><th>Ground observation at Syowa Station</th></tr>
<tr><td>1</td><td>Study of interaction processes between auroral electrons and electrostatic plasma waves in the HF range such as UHR wave, electron cyclotron harmonic wave, and Z-mode wave</td><td rowspan="2">· Energy spectrum (50eV–15keV), pitch angle distribution and flux modulation (1–5MHz range) of auroral electrons
· Spectrum of plasma waves in the frequency range 1–5MHz (electric component)
· Magnetic field (field-alinged current)
· Electric field
· Electron density</td><td rowspan="2">· Electromagnetic waves in the HF range
· Auroral TV image
· Auroral intensity
· Spatial distribution of precipitating electrons (multi-beam riometer)
· Magnetic variation</td></tr>
<tr><td>2</td><td>Study of generation and propagation mechanisms of auroral kilometric radiation (AKR)</td></tr>
<tr><td>3</td><td>Study of interaction processes between auroral electrons and electrostatic plasma waves in the ELF-VLF range such as LHR wave, electrostatic ion cyclotron wave and ion acoustic wave</td><td rowspan="3">· Energy spectrum (50eV–15keV), pitch angle distribution and flux modulation (0.1–10kHz range) of auroral electrons
· Spectrum of plasma waves in the frequency range 0.2–10kHz (electric and magnetic components)
· Magnetic field (field-aligned current)
· Electric field
· Electron density
· Electron density irregularity in the frequency range 20Hz–10kHz.</td><td rowspan="3">· Electromagnetic waves in the ELF-VLF range
· Auroral TV image
· Auroral intensity
· Spatial distribution of precipitating electrons (multi-beam riometer)
· Magnetic variation</td></tr>
<tr><td>4</td><td>Study of generation and propagation mechanisms of auroral hiss</td></tr>
<tr><td>5</td><td>Study of generation mechanism of electron density irregularity</td></tr>
</table>

Table 2. Scientific aims of the S-310JA-12 rocket experiment. The rocket will be launched into pulsating aurorals.

	Scientific aim	*In situ* measurement on board the S-310JA-12 rocket	Ground observation at Syowa Station
1	Determination of modes of plasma waves in the HF range and study of interaction processes between these waves and auroral electrons	· Energy spectrum (50eV–15keV), pitch angle distribution and flux modulation (1–5MHz range) of auroral electrons · Spectrum of plasma waves in the frequency range 1–5 MHz (electric component) · Magnetic field · Electric field (field-alinged current) · Electric field	· Electromagnetic waves in the HF range · Auroral TV image · Auroral intensity · Spatial distribution of precipitating electrons (multi-beam riometer) · Magnetic variation
2	Determination of modes of plasma waves in the ELF-VLF range and study of interaction processes between these waves and auroral electrons	· Energy spectrum (50eV–15 keV), pitch angle distribution and flux modulation (0.1–10 kHz range) of auroral electrons · Spectrum of plasma waves in the frequency range 0.2–10kHz (electric and magnetic components) · Magnetic field (field-aligned current) · Electron density irregularity in the frequency range 20Hz–10kHz	· Electromagnetic waves in the ELF-VLF range · Auroral TV image · Auroral intensity · Spatial distribution of precipitating electrons (multi-beam riometer) · Magnetic variation · Ionospheric electric field (VHF doppler radar)
3	Study of generation mechanism of auroral chorus		
4	Study of generation mechanism of electron density irregularity		
5	Study of field aligned current, ionospheric electric field and magnetic variation associated with pulsating aurora	· Electric field · Magnetic field · Auroral electron · Electron density	· Ionospheric electric field (VHF doppler radar) · Auroral TV image · Magnetic variation

in pulsating auroras so far. The scientific aims of the S-310JA-12 rocket experiment are summarized in Table 2.

3. Launching Condition

The S-310JA-11 rocket will be launched into auroral arcs, while the S-310JA-12 rocket will be launched into pulsating auroras. The payload is the same for these two rockets so that differences between the wave-particle interaction processes in two types of auroras can be easily compared. The launch window for these rockets is as follows:

S-310JA-11	April 1–30, 1985
	2200–0300 LT (1900–2400 UT)
S-310JA-12	May 1–31, 1985
	0100–0600 LT (2200–0300 UT)

The magnetic local time at Syowa Station is nearly equal to the universal time (MLT = UT+15 min). Both the rockets will be launched along the magnetic field line. If possible, the S-310JA-12 rocket will be launched when the EXOS-C satellite traverses over Syowa Station.

4. Organization and Personnel Involved in This Experiment

The organizations involved in this experiment are eleven as listed below:
National Institute of Polar Research (NIPR)
Radio Research Laboratories (RRL)
Institute of Space and Astronautical Science (ISAS)
Department of Electrical Engineering, Kyoto University
Radio Atmospheric Science Center, Kyoto University
Department of Physics, Tohoku University
Faculty of Engineering, Kobe University
Department of Electrical Engineering, Kanazawa University
Laboratory of Space Science, Tokai University
Geophysical Research Laboratory, University of Tokyo
Research Institute of Atmospherics, Nagoya University

The investigators of each payload are as follows:

(1) Energy spectrum measurement of auroral particles (ESP)

P.I.	H. YAMAGISHI	(NIPR)
Co.I.	H. MIYAOKA	(NIPR)
	M. EJIRI	(NIPR)
	T. MUKAI	(ISAS)
	E. SAGAWA	(RRL)
	N. KAYA	(Kobe Univ.)

(2) Plasma wave measurement in low frequency range (PWL)

P.I.	I. KIMURA	(Kyoto Univ.)
Co.I.	K. HASHIMOTO	(Kyoto Univ.)
	I. NAGANO	(Kanazawa Univ.)
	T. MATSUO	(Kyoto Univ.)
	H. MATSUMOTO	(Kyoto Univ.)
	M. TSUTSUI	(Kyoto Univ.)
	T. KAMADA	(Nagoya Univ.)
	H. YAMAGISHI	(NIPR)

(3) Plasma wave measurement from number density fluctuation (PWN)

P.I.	H. MORI	(RRL)
Co.I.	E. SAGAWA	(RRL)
	I. IWAMOTO	(RRL)
	T. OGAWA	(RRL)

(4) Plasma wave measurement in high frequency range (PWH)

P.I.	H. OYA	(Tohoku Univ.)
Co.I.	A. MORIOKA	(Tohoku Univ.)
	T. OHARA	(Tohoku Univ.)
	H. MIYAOKA	(NIPR)
	T. ONO	(NIPR)

(5) Number density of measurement of electrons by impedance probe (NEI)

P.I.	T. TAKAHASHI	(Tohoku Univ.)
Co.I.	H. OYA	(Tohoku Univ.)
	A. MORIOKA	(Tohoku Univ.)
	Y. WATANABE	(ISAS)
	T. OBAYASHI	(ISAS)
	H. YAMAGISHI	(NIPR)

(6) Auroral electric field measurement (AEF)

P.I.	T. OGAWA	(Kyoto Univ.)
Co.I.	H. FUKUNISHI	(NIPR)
	H. YAMAGISHI	(NIPR)

(7) Magnetic field measurement (MGF)

P.I.	H. FUKUNISHI	(NIPR)
Co.I.	R. FUJII	(NIPR)
	S. KOKUBUN	(Univ. of Tokyo)
	F. TOYAMA	(Tokai Univ.)
	I. AOYAMA	(Tokai Univ.)

(8) Horizon sensor (HOS)

	M. ISHIDO	(Kobe Univ.)

At Syowa Station, the following personnel will participate in the launching operation:

Name	Function
H. FUKUNISHI	Project scientist
H. YAMAGISHI	Chief experimenter
I. AYUKAWA	Payload engineer
Y. ITO	Engineer (rocket)
H. ITAKURA	Engineer (radar)
T. FURUDATE	Engineer (telemeter)

5. Payload Information

5.1. Description of the instruments

Electrostatic and electromagnetic plasma waves are measured in an extremely wide frequency range from 0.5 Hz to 12 MHz by the four kinds of instruments: MGF, AEF, PWL and PWH. Corresponding to these plasma wave measurements, electron density irregularities and flux modulations of precipitating auroral electrons from 0.2 Hz to 4 MHz are measured by three kinds of instruments: ESP, PWN and NEI. These data will provide conclusive information on wave-particle interaction processes in auroras. Summarized in Fig. 1 are frequency ranges of the instruments and auroral phenomena to be measured by these instruments.

5.1.1. Energy spectrum measurement of auroral particles (ESP)

Energy spectra of auroral electrons are measured by a quadraspherical analyzer with three FOV directions (30, 90 and 150°) to the rocket axis. Fluctuations of auroral electron fluxes at energies of 500 eV, 2 and 8 keV are also measured by supplying constant voltage to the analyzer. Both measurements are time-shared, *i.e.*, one 0.64-s interval for 32-step energy spectrum measurement from 50 eV to 16 keV,

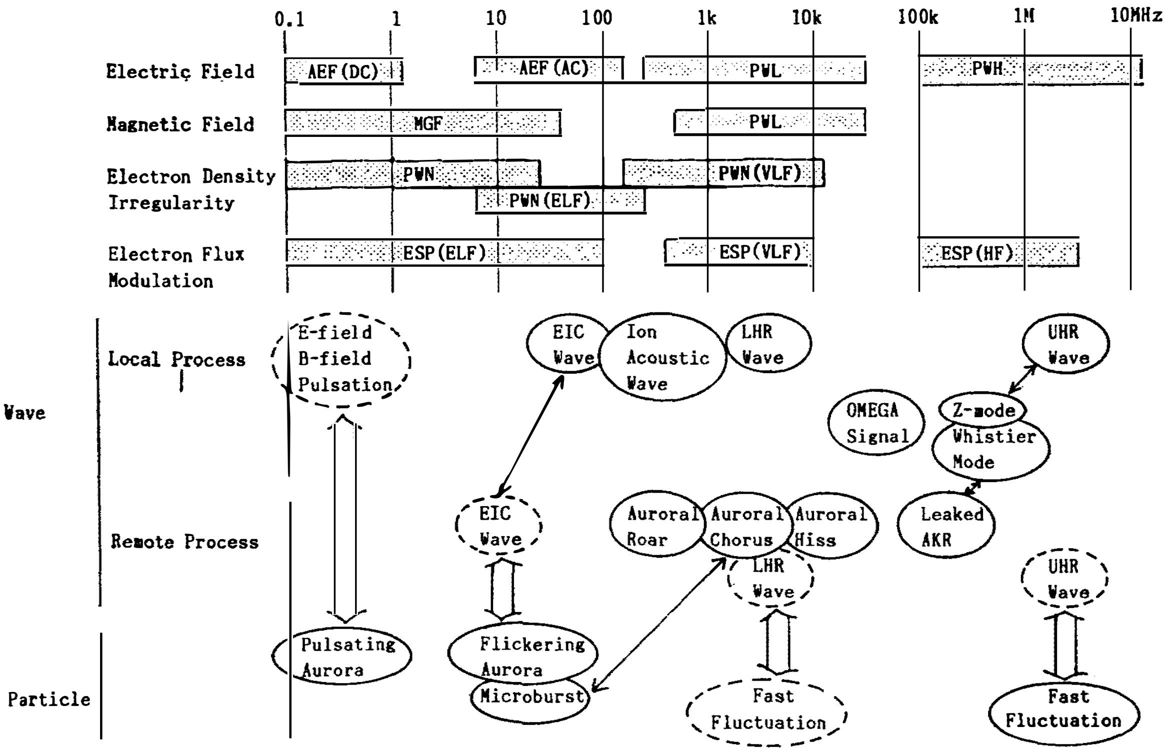

Fig. 1. Frequency ranges covered by the instruments on board the S-310JA-11 and -12 rockets, and wave-particle interaction processes to be measured by these instruments.

and three 0.64-s intervals for flux measurement at 500 eV, 2 keV and 8 keV. During the time interval for the flux measurement, electron flux fluctuations up to 100 Hz are directly telemetered to the ground by the PCM telemeter, while fast fluctuations in the frequency ranges 320 Hz–8 kHz and 100 kHz–4.0 MHz are analyzed by an on-board data processor and then the auto correlation function averaged in the 0.64 s time window is telemetered to the ground. These fluctuations in electron fluxes are compared with plasma waves simultaneously observed on the same rocket in order to study wave-particle interaction processes on auroral field lines.

5.1.2. Plasma wave measurement in low frequency range (PWL)

Electric and magnetic field components of plasma waves in the VLF range are measured by a pair of dipole antennas (2.5 m tip to tip) and a search coil sensor 25 cm long, respectively. The instrument consists of a two-channel sweep analyzer for simultaneous measurement of electric and magnetic field components, and a single channel wideband receiver for measurement of electric field component. The frequency range, the resolution and the sweep period of the sweep analyzer are 500 Hz–12.6 kHz, 400 Hz, and 160 msec, respectively. The frequency range of the wideband receiver is 200 Hz–8.0 kHz. The wideband data are telemetered by using a wideband channel of the telemeter which is time-shared with PWN.

5.1.3. Plasma wave measurement from number density fluctuation (PWN)

Fluctuations of electron densities in the ELF (5–300 Hz) and VLF (200 Hz-8.0 kHz) ranges are measured by a Faraday cup. The fluctuations in the ELF range are telemetered using the IRIG-FM band 14, while the fluctuations in the VLF range are telemetered using a wideband channel, which is time shared with PWL as mentioned above. Relative electron density profiles are obtained by utilizing the first grid of the Faraday cup as a fixed biased probe. The time variations of electron fluxes integrated over up to 90 eV are also measured by this instrument.

5.1.4. Plasma wave measurement in high frequency range (PWH)

The electric field component of plasma waves in the HF range (100 kHz–12 MHz) is measured by a pair of dipole antennas (2.5 m tip to tip) and a synthesized sweep receiver with a frequency resolution of 1.5 kHz and a sweep period of 2.56 s. This instrument can measure both electrostatic and electromagnetic waves on auroral field lines.

5.1.5. Electron number density measurement by an impedance probe (NEI)

Number density of electrons in the range of 2×10^3–5×10^6/cm^3 is measured every one second by using a monopole antenna with a length of 1.2 m as an impedance probe.

5.1.6. Auroral electric field measurement (AEF)

A pair of spherical probes, which are separated by 2.6 m and extending perpendicular to the rocket axis, measures DC electric field in the auroral ionosphere. Electric field fluctuations in the frequency range of 10–200 Hz are also measured by this instrument.

5.1.7. Magnetic field measurement (MGF)

The instrument is a fluxgate magnetometer with a tri-axial ring-core type sensor. The sensor is extended from the rocket body by a rigid boom 25 cm in length. The full scale and resolution of the magnetometer are 60 000 and 2 nT. The data are given in digital form (16-bit word) and telemetered by the PCM channel. The sampling rate is 100 Hz. This magnetometer can measure both the ionospheric current and the field-aligned current. This magnetometer is also used as a geomagnetic attitude sensor.

5.1.8. Horizon sensor (HOS)

This sensor measures infra-red flux of 8–20 μm, radiated from CO_2. By detecting abrupt change in flux when the FOV of the sensor crosses the horizon, it is possible to get information on the rocket attitude.

5.2. Composition of the payload

Composition of the payload is shown in Fig. 2, and the orientation diagram of the sensors is shown in Fig. 3.

5.3. Payload telemetry

The telemeter used in this rocket is a hybrid type telemeter which can transmit simultaneously three kinds of signals: IRIG FM (bands 2–14) signal, AM(SSB) signal with bandwidth of 10 kHz, and PCM signal of 25.6 kbps. Allocation of channels for the FM telemetry is shown in Table 3, and the PCM format is given in Table 4.

5.4. Power requirement and weight

Two sets of Ni-Cd batteries are prepared for each rocket. One is used for the power supply to the scientific instruments, and the other is used for the common instruments: radar transponder, telemeter, electric timer and magnetometer. The power requirement and weight of these instruments are shown in Tables 5 and 6,

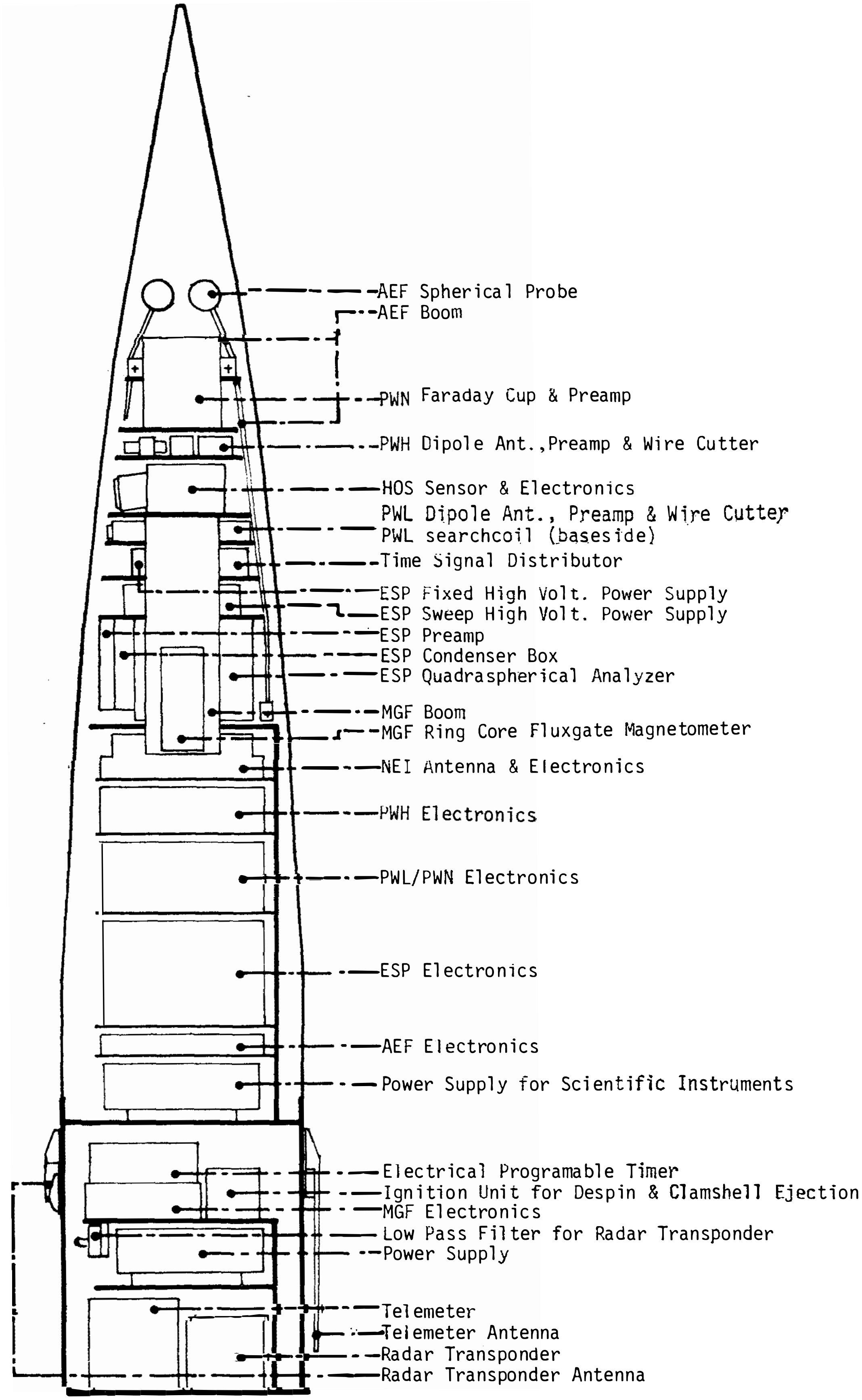

Fig. 2. Payload configuration of the S-310JA-11 and -12 rockets

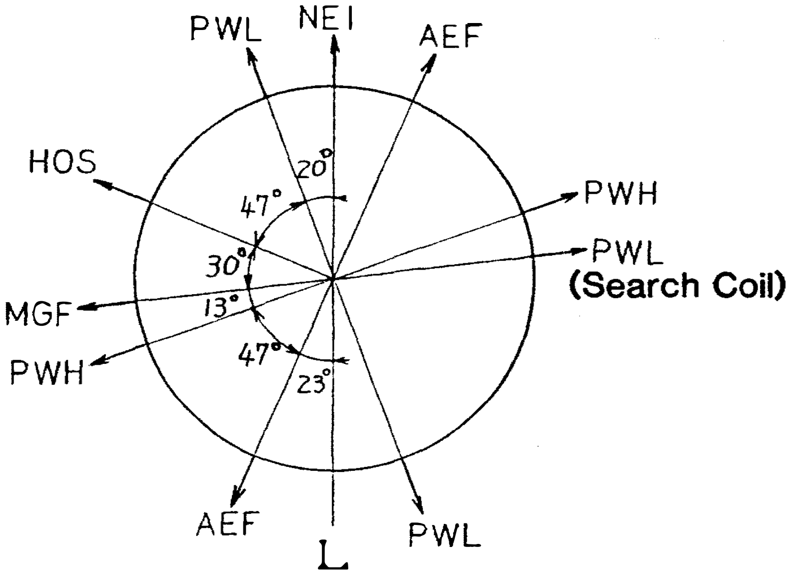

Fig. 3. Orientation diagram of sensors and antennas of the S-310JA-11 and -12 rockets.

Table 3. Allocation of FM telemetry channels.

Band	Response	Data
15*		PWL/PWN-wideband
14	330	PWN-AC
13	220	AEF-AC
12	160	PWH-S
11	110	PWH-M
10	81	NEI-S
9	59	PWN-FLUX
8	45	PWN-DC
7	35	HOS
6	25	NEI-M
5	20	AEF-DC
4	14	PWL/PWN/AGC
3	11	MGF-H/EPT
2	8.4	MGF-Z

respectively.

5.5. Rocket specifications and trajectory

The specifications of S-310JA-type rocket are summarized in Table 7. The predicted flight trajectory is shown in Fig. 4, while Table 8 gives the time sequence of the payload operation.

Table 4. PMC telemetry format.

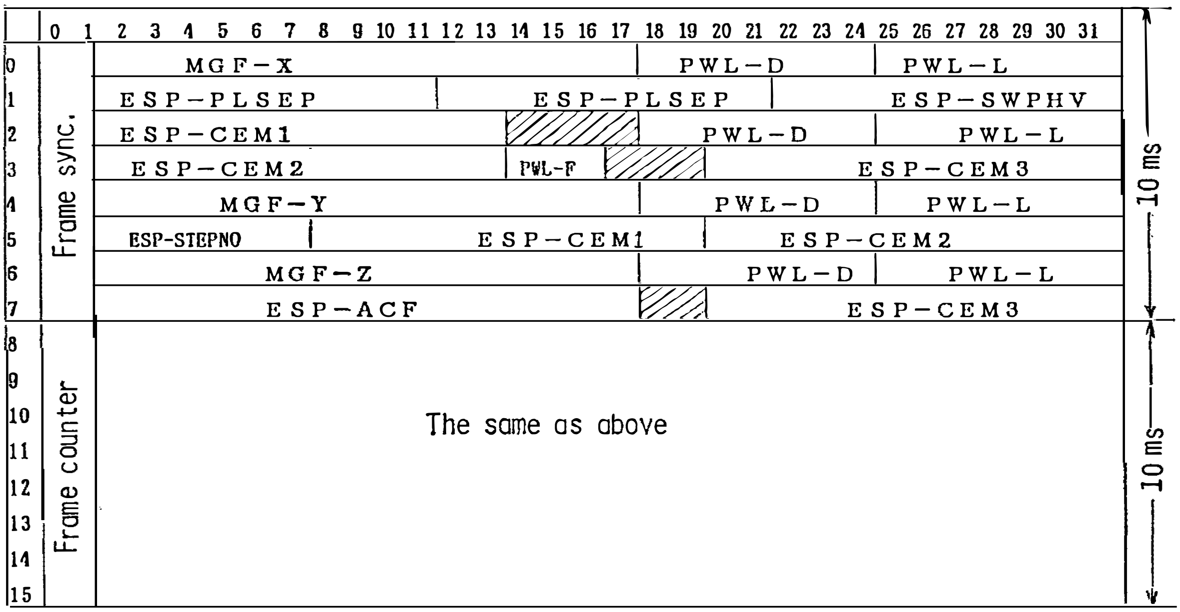

Table 5. Power requirement and weight of scientific instruments on board the S-310JA-11 and -12 rockets.

Name of instrument	Power requirement +18V (mA)	Power requirement −18V (mA)	Power requirement +9V (mA)	Weight Electronics (kg)	Weight Sensor (kg)
ESP	300	150	1 500	3.0	3.9
PWL/PWN	320	280		2.5	3.0
PWH	230	180	100	1.9	0.8
NEI	150	100		1.3	
AEF	100	100		1.2	1.3
HOS	10	10		1.0	
Battery	—	—	—	4.8	
Total	1 100	820	1 600	24.7	

Table 6. Power requirement and weight of common-use instruments on board the S-310JA-11 and -12 rockets.

Name of instrument	Power requirement +18V(A) (mA)	Power requirement −18V (mA)	Power requirement +18(B) (mA)	Weight (kg)
Telemeter	800	140		2.4
Radar transponder			600	2.2
Electrical timer	200			1.5
MGF		100	350	2.2
Battery	—	—	—	4.8
Total	1 000	240	950	13.1

Table 7. Specifications of the S-310JA-type rocket in case that the rocket is launched with an initial elevation angle of 80°.

Length of clamshell	1140 mm
Length of payload	1920 mm
Length of motor	5157 mm
Total length	7077 mm
Maximum diameter	310 mm
Weight of payload	70–80 kg
Weight of thruster	~470 kg
Total weight	~700 kg
Thrust time	~30 s
Flight time	~7 min
Apex	~210 km*
Spin rate (Initial)	3–4 Hz
(Despun)	~1 Hz

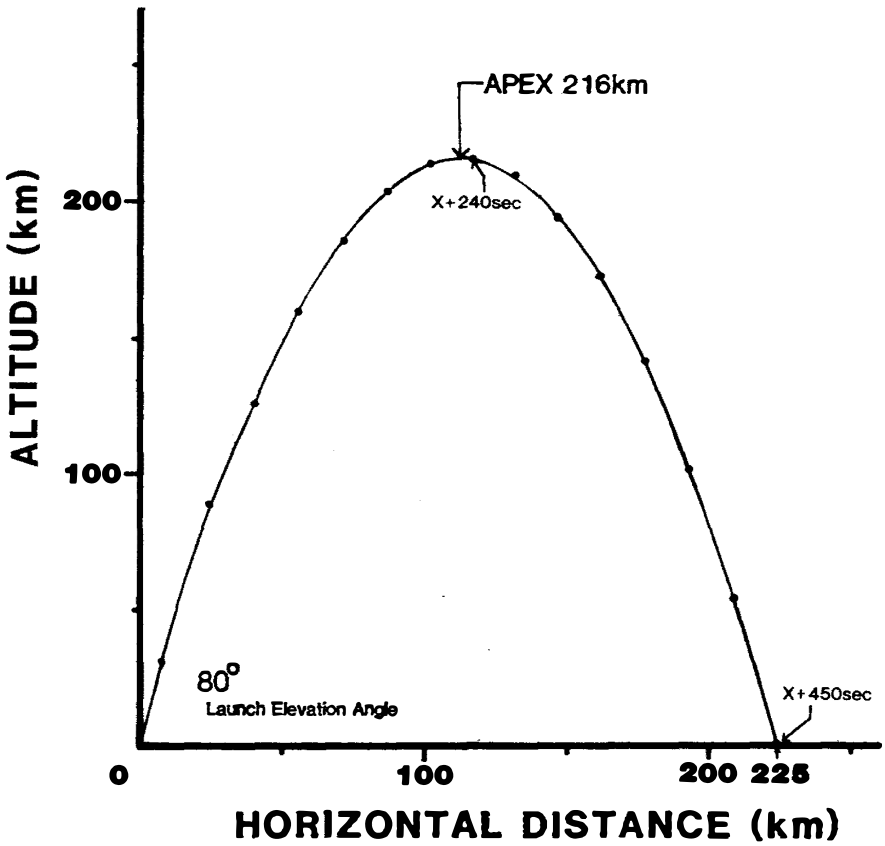

Fig. 4. Calculated flight trajectory of the S-310JA-11 and -12 rockets.

Table 8. Flight events of the S-310JA-11 and -12 rockets.

Flight events	Time (s)	Altitude (km)	Range (km)
Motor ignition	0	0	0
Motor burnout	30	32.5	8
Despin	45	59	25
Clamshell ejection	51	70.2	—
Deployment of PWL dipole antenna, PWH dipole antenna, NEI monopole antenna	53	73.5	—
Deployment of MGF boom, PWL searchcoil boom	54	75.2	—
Deployment of AEF double probe	55	76.9	—
ESP High voltage power on	105	148	52
PWN Amplifier gain change	107	150	—
Apogee	235	225	116
Impact	460	0	233

6. Rocket-ground Cooperative Observations

Ground-based observations of auroral phenomena at Syowa Station are carried out during the rocket experiment. Auroras are observed by all-sky camera, all-sky TV camera, meridian scanning photometer and zenith photometer, while magnetic variations are observed by fluxgate and search coil magnetometers. ELF-VLF emissions are measured by multi-channel intensity recorder and wide-band receiver. Ionospheric absorption is measured by both single-beam riometer and multi-beam riometer. The ionospheric electric field is continuously monitored by VHF doppler radar with two beams, while the vertical profile of electron density is measured by ionosonde.

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We thank Profs. T. NAGATA and T. HIRASAWA of the National Institute of Polar Research, and Prof. I. KIMURA, chairman of the Committee on Antarctic Rocket Observation and other members of the Committee for their kind support and valuable discussions. We are also grateful to Dr. T. OGAWA and Messrs. I. AYUKAWA, T. KOJIMA, Y. ITO, T. FURUDATE and H. ITAKURA, the rocket members of the 26th Japanese Antarctic Research Expedition party for their efforts in actual preparations for the rocket experiment at Syowa Station.

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