Memoirs of the Faculty of Science, Kyoto University, Series of Physics, Astrophysics,
Geophysics and Chemistry, Vo.l XXXIV, No. 3, Article 12, 1974.

# A BALLOON BORNE LIQUID NITROGEN COOLED INFRARED RADIOMETER

BY

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(*Received April 19, 1974*)

## ABSTRACT

An infrared radiometer has been built to observe the galactic diffuse light in near infrared region. Whole telescope is cooled by liquid nitrogen so as to reduce the intense emission from the telescope. It was launched by a balloon on Oct. 9, 1971. Small size irregularities were found to be present in the OH airglow emission and of great obstacle for the observation of the galactic light.

These irregularities are due to winds, gravity wave and turbulence in the upper atmosphere, and hence the observation of the OH airglow emission would give a useful probe for the studies of dynamic properties of the thermosphere.

## 1. Introduction

The global structure of our galaxy has been investigated by various methods of observations. The observations of 21 cm radio emission have revealed clearly the spiral pattern of interestellar hydrogen clouds.[1] O and B type stars which are bright enough to be observed in long distances have been used to investigate the stellar distribution.[2] Several authors have measured diffuse integrated light from the stars which show some structure in the intensity distribution.[3],[4] Since these observations by visible light are seriously affected by the interstellar extinction, the observable distance is badly limited; i.e. less than 1 or 2 Kpc.

The galaxy would become relatively transparent to the infrared radiation, for the interestellar extinction decreases rapidly with wavelength. The diffuse infrared light would therefore reveal the stellar distribution in the galaxy to much more distant region. However, the stellar spectra show a steep decrease in the infrared region beyond 1 micron. Near infrared region is optimum to be observed.

We have built a radiometer to observe the diffuse infrared radiation of the galaxy which is useful to know the global distribution of the galactic stellar components. But the observation is strongly disturbed by the OH airglow and thermal emissions of the atmosphere and the telescope itself. The intensities of these background radiations are shown in Fig. 1. The infrared radiation from the galactic plane is roughly estimated and compared with the backgrounds in the same figure. The airglow dominates in the wavelengths between 1 and 2 microns, while the thermal backgrounds become serious above 2 microns. In order to avoid the atmospheric emission and absorption, the observation must be done in upper or out of the atmosphere. The effect of OH airglow can be elliminated only by

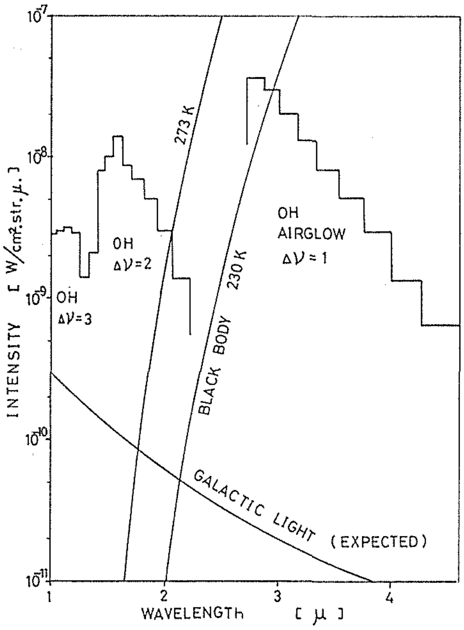

Fig. 1. Estimated intensities of the galactic light and background radiations; the OH airglow and thermal emission from the telescope wall.

the rocket borne experiment. However, a limited window is available in the OH airglow emission between the vibration bands of $\Delta$ v=1 and $\Delta$ v=2, providing a emission free window from 2.2 to 2.7 microns through which we can observe the extraterrestrial radiation.

Whole components of the telescope; the mirror, the telescope wall, the chopper as well as the detector should be cooled by liquid nitrogen to reduce the thermal radiations to be ineffective enough. Originally the radiometer was designed for a rocket observation to escape from the airglow emission. We changed however to observe it at balloon altitude, discriminating the galactic component from the strong airglow background by differential method, i.e. detection of inhomogeneous component superposed on the uniform background. The balloon is more favorable for such an observation as to scan large area of the sky which needs long time.

## 2. Liquid nitrogen cooling of the telescope

Cryogenical devices for cooling the telescope by liquid nitrogen is illustrated in Fig. 2. The telescope wall is made of a copper tube which is surrounded by liquid nitrogen vessel. At the upper part of the vessel molecular sieves are packed to make vacuum more complete by adsorption when liquid nitrogen is filled.

The mirror made of Kanigen coated aluminum is fixed at the bottom of the tube. The detector system, i.e. the detector, the filter, the chopper and its driving motor are mounted inside an aluminum tube which is supported by two plates of aluminum to the telescope wall.

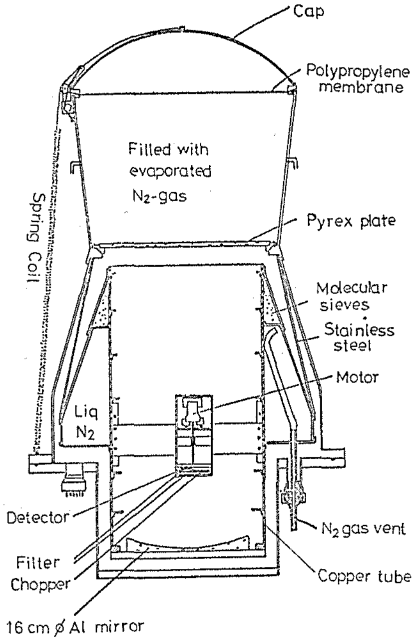

*Fig. 2. General view of the radiometer (about 70 cm in height)*

The whole system is hanged by a thin stainless steel cone from the lowest edge of the liquid nitrogen vessel to the upper edge of the vacuum vessel. The heat flow can be effectively insulated by its thinness and distance between the outer wall and the inner vessel.

The outer wall is tapered to the top to fit the shape of the rocket nose cone. In the case of rocket experiment which was originally planned, the telescope was expected to be covered at the top by a lid for keeping vacuum, which should be opened in the observation.

For the balloon borne observation several modifications are required. The top lid is replaced by a transparent window, for the vacuum must be kept in the observation from residual atmosphere. A fused quartz of 6 mm thick had been first used for the window. It was crashed in the test operation just before the flight. We were compelled to replace it by a pyrex glass of 11 mm thick.

To reduce the scatter-in of the atmospheric background emission from the ground, a hood blackened inside with lusterless paint is extended from the top of the cryostat. The hood is covered by a cap which will be opened by a spring at the beginning of level flight. The front of hood is sealed by a thin polypropylene membrane to prevent water vapor from flowing in and frosting on the glass window cooled by the cold cryostat vessel. The volume inside the hood is connected by a vynil tube to one of the pipe of vent gas to make the pressure balance with environmental one without introducing the atmosphere containing water vapor into the inner space.

The whole components in the telescope; the mirror, the detector system and the telescope wall can be cooled efficiently down to liquid nitrogen temperature with a delay of about one hour after filling up liquid nitrogen. The cooling is kept for about 10 hours by 6 litres liquid nitrogen, when it is put in the room temperature. At balloon altitudes, where the environmental temperature is as low as —50°C, the keeping time would be considerably lengthened.

## 3. The optical system

### a) Light collecting mirror

For the purpose of observing the galactic infrared radiation with about 2.5° beam width, a simple optical system has been adopted, i.e. PbS detectors are mounted on the direct focal plane of a spherical mirror with 16 cm diameter and with a rather small focal ratio of 0.7. The mirror being made of Kanigen coated aluminum alloy has some merits such as mechanical strength for the launching shock and the good thermal conductivity. The reflectivity of the Kanigen coated surface, however, has shown a rather low value than 70% in near infrared wavelength, so the surface is aluminized to improve the reflectivity up to 90% or higher.

The aberration of the spherical mirror has been calculated by the light ray tracing method with an electronic computor. An example of the spot diagram of the mirror is shown in Fig. 3 in the case of an incident angle of 2.5° off axis. The estimated intensity distribution on the focal plane by the same method is also illustrated in Fig. 4 in the case of a uniformly extended source with a radius of 2.5°.

Dimensions of two detectors are $5\times 5$ mm$^2$ and $4\times 6$ mm$^2$ respectively. The measured patterns of their field of view are roughly $2.5°\times 2.5°$ and $2°\times 3°$ as shown in Fig. 5. The product of the effective solid angle and area is about 0.3 cm$^2$·ster.

### b) Chopping system

The observation in the near infrared region is seriously suffered from the intense emission of the airglow even at the balloon altitude. In order to cancel this strong emission by comparing with the neighboring sky, we mount on the focal plane two detectors 5° apart each other. A rotating blades chop the incoming beam onto the two detectors with a phase difference of a half wave. Signals from the two detectors are added after adjusting their response level, then the uniform background radiation can be eliminated and only differential component of the two neighboring sky is scooped up. We had, however, to abandon the method of this sky cancellation because one of the pair detectors was collapsed by an accident and the two detectors used had quite different characteristics concerning wavelength dependences and temperature dependences.

The chopper plate is driven by a motor which has been specially treated for low tem-

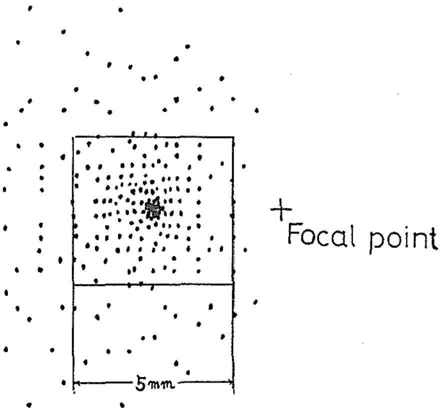

Fig. 3. Aberration pattern of the 16 cm (F/0.7) spherical mirror for 2.5° off axis rays.

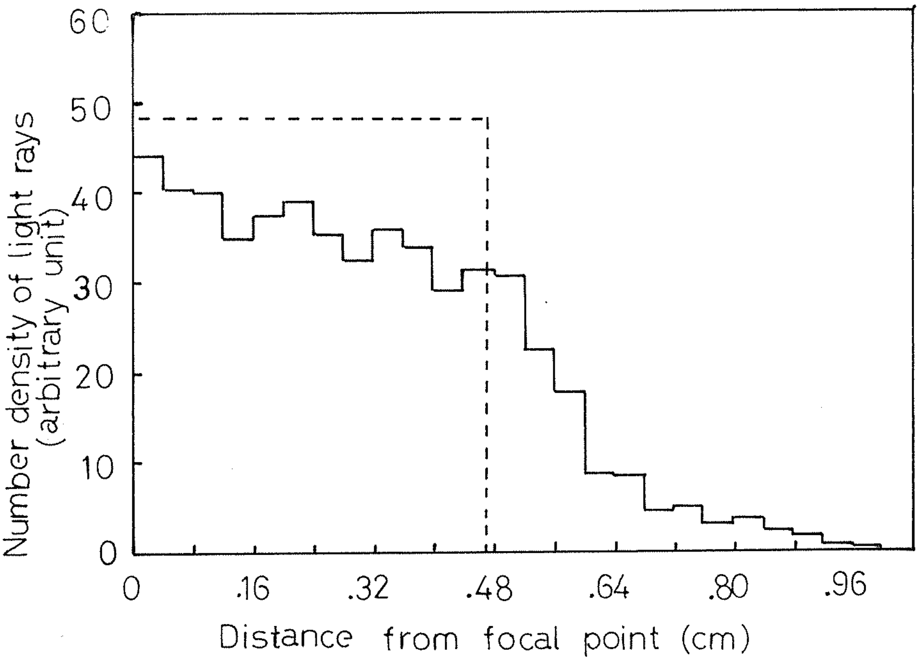

Fig. 4. Intensity distribution on the focal plane for a diffuse object with angular diameter of 2.5°.

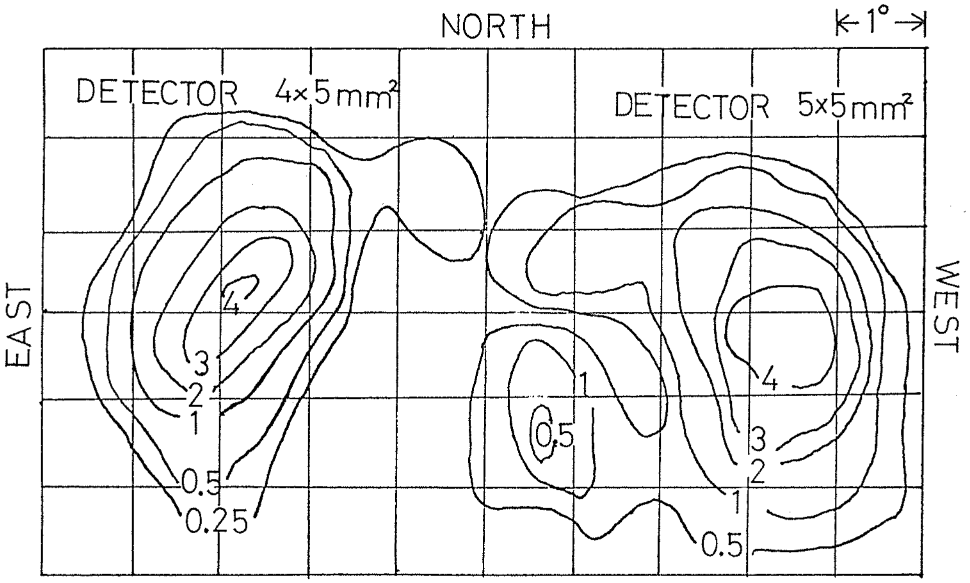

Fig. 5. Measured pattern of the field of views of the detector system.

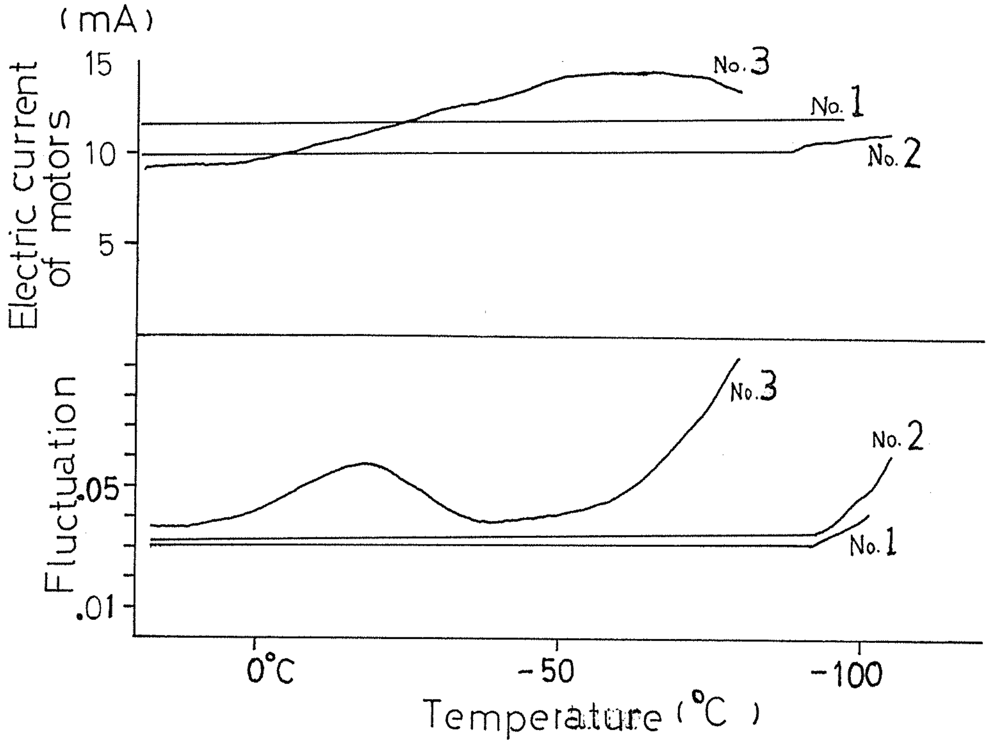

Fig. 6. Temperature dependence of driving currents and fluctuating currents of $MoS_2$ lubricated motors. No. 1 was used in the observation.

perature operation by the procedure; micro size powder of $MoS_2$ was chemically coated on the bearing, after the oil was washed out. Low temperature characteristics have been checked by measuring the driving current and its stability. (see Fig. 6).

The motor was thermally insulated by the teflon supporter not to be cooled to too low temperature, in balance with Joule heat of driving current. The shaft connecting the motor axis to the chopper plate is long enough for the choppper plate not to be warmed by the heat from the motor.

### (c) PbS Detectors

Two PbS detectors (PbS-1, and PbS-2) are set at the focal plane of the spherical mirror, as was described in the preceding section. The PbS-1 has $5 \times 5\,mm^2$ effective area, whose optimum operating temperature is about 77°K (the liquid nitrogen temperature) and the PbS-2 is a detector for the room temperature use having $4 \times 6\,mm^2$ effective area. We were obliged to choose these different types of PbS cells, because one of the former type detectors was collapsed by an accident in the experiment.

A carbon resistor is used as a thermister to monitor the temperature of the detectors. The calibrated curve of temperature-voltage relation is shown in Fig. 7, in which the measuring circuit is also inserted.

At the room temperature, the ohmic resistance of the detector for the liquid nitrogen temperature use (PbS-1) and that for the room temperature detector use (PbS-2) are 200kΩ

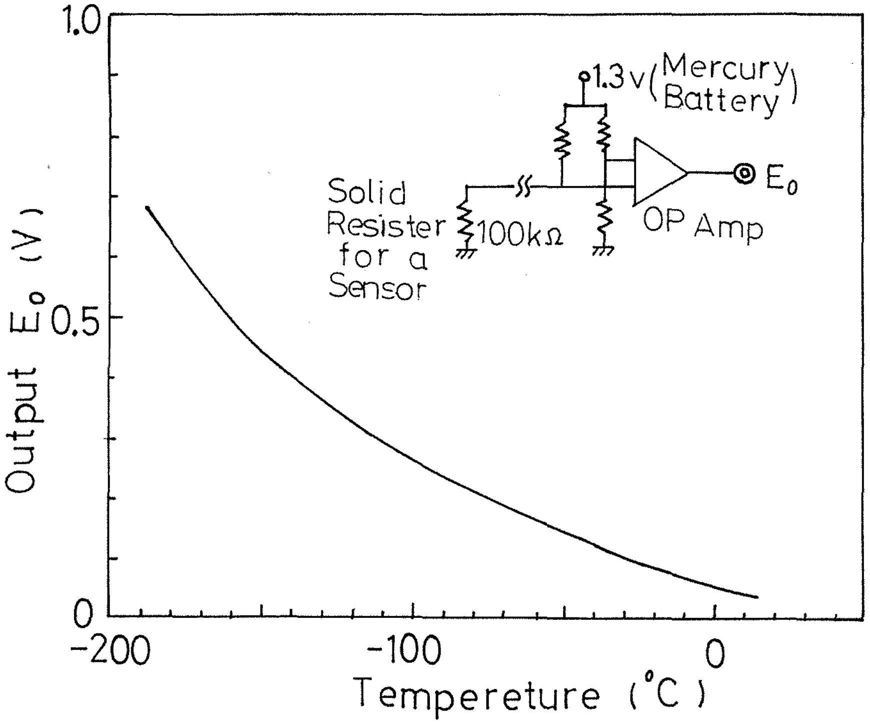

Fig. 7. Calibration curve of the thermister.

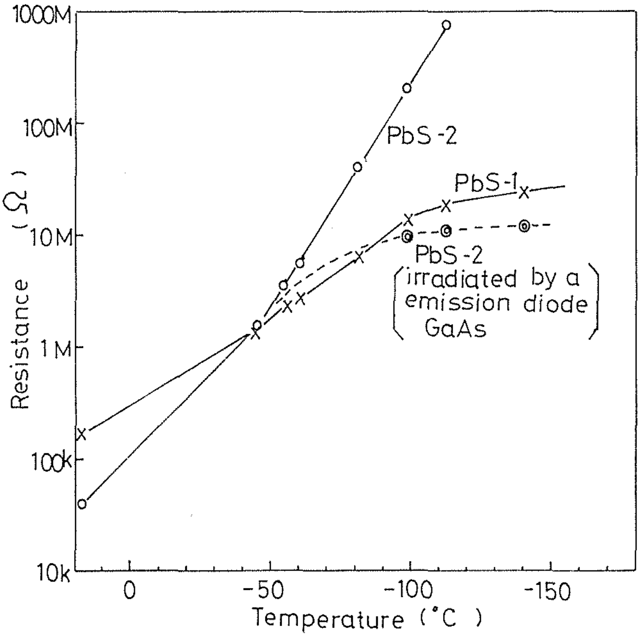

Fig. 8. Temperature dependences of ohmic resistances of the PbS detectors.

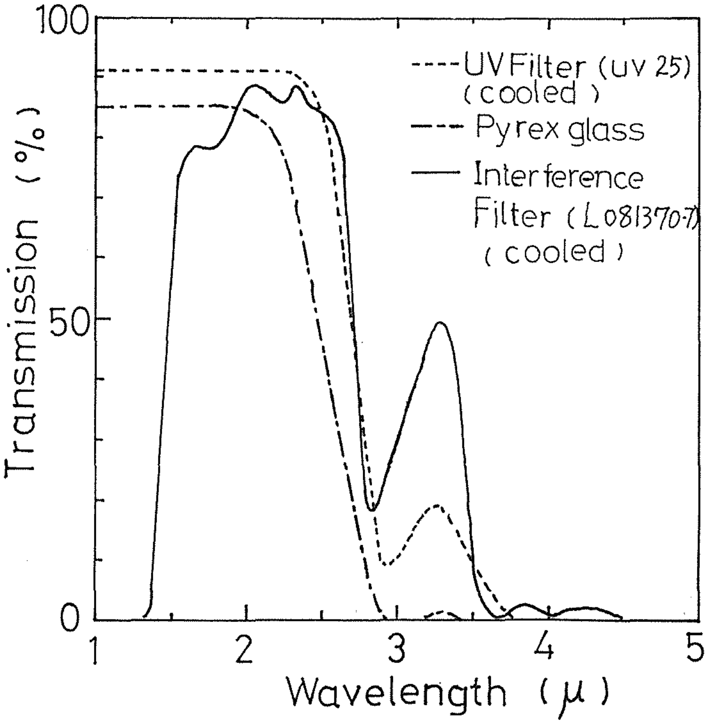

Fig. 9. Transmissions of the filters and the pyrex glass window.

and 50 KΩ respectively. When they are cooled, however, their values are inverted below the temperature of −50°C as shown in Fig. 8.

As the operating bias current to the detectors is supplied through a 20 MΩ resistor from a 90 volts battery, and as the input impedance of the pre-amplifier is about 10 MΩ the PbS-2 would become useless below about −80°C by impedance mismatching. But we could avoid the difficulty by reducing the detector's resistivity by means of a subsidiary irradiation onto the detector. For this purpose, the detector was illuminated from the backside by a GaAs-emission diode. The detector resistivity was successfully reduced to 10 MΩ(see Fig. 8) and the noise level could be also reduced greatly. The diode emits near infrared light having a sharp maximum at about 0.9 μ, completely ineffective for our observation.

### d) Filters

Considering the wavelength dependence of the detector sensitivity and the spectral distribution of the airglow emission, the observed wavelength is selected by two kinds of filters, one is an interference-filter and the other is a UV glass filter, whose spectral transmission curves are presented in Fig. 9. The transmission of the Pyrex glass of 11 mm thick is also shown in the same figure. By the combination of the filter transmissions and the detector sensitivity, the center of the effective wavelength is 2.2 μ and the bandwidth is about 0.8 μ for both detectors. The OH airglow window was given up to aim because of insufficient sensitivity of the detector for the Galactic light intensity.

## 4. Electronics

There were five signals to be transmitted by a telemeter; those of the two PbS detectors, the thermister, the atmospheric pressure gauge and the geomagnetic aspectometer (G.A.). The PbS-1 was to measure the absolute brightness of the airglow emission with relatively low gain and the PbS-2 was to detect the detailed variation of the emission with much higher gain. One of the telemeter channels was occupied by the high gain signal from the PbS-2. The other channel was used for the G.A. signal, and the last one was time-shared by the PbS-1, the thermister and the pressure gauge.

Three channels were available for the remote control. One was used to start and stop the rotation of the gondola and also to light the standard lamp for the calibration of the detector sensitivities. The other was used to shift the offset voltage of the DC-amplifier for the high gain detector so as to set its signal level in the dynamic range of the telemeter. The last one was used to adjust the phase of the reference signals. The block diagram of the electronics system is shown in Fig. 10.

## 5. Flight

The radiometer was launched to observe the near infrared galactic light from the Sanriku Balloon Base (of the Institute of Space and Aeronautical Science, Tokyo University) at 18 : 30 on October 9, 1971, by a balloon of 5000 m$^3$. The balloon reached the ceiling altitude of 27 Km after about an hour and kept its level flight for 11 hours until it was cut down at the sunrise in the next morning.

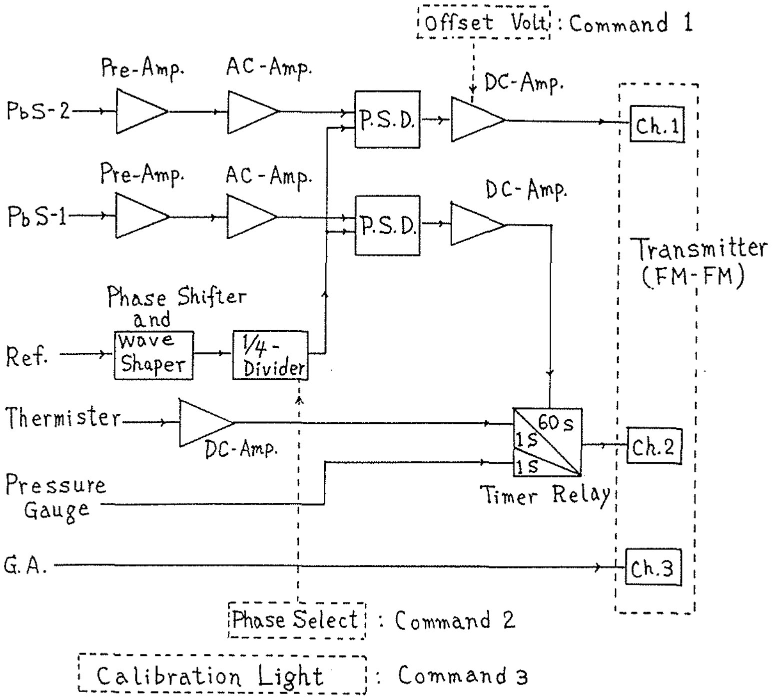

Fig. 10. Block diagram of the electronics system.

Since the radiometer had been first designed for a rocket borne experiment, the mechanical strength for the launching shock was more than enough. On the level flight, the radiometer was fixed at an elevation angle of 30°, and rotated azimuthally with a constant speed; one rotation in about 2 minutes. The attitude of the radiometer was monitored by the geomagnetic aspectometer (G.A.).

Whole system operated normally except a few troubles. The phase locking of the reference signal was slightly unstable. The temperature in the cryostat arose to —50°C in the level flight, the signal level of the low gain channel (PbS-1) became too low to detect the intensity variation.

Unexpectedly, the signals of the high gain channel (PbS-2) have shown significant fluctuations in the airglow intensity. The observed results are shown in Fig. 11. The fluctuation patterns show good recurrency with the rotation of the radiometer in azimuth, and change gradually with time. There are various scales of irregularities from relatively large variations with angular sizes of several tens degrees to small ripples with sizes of the order of 3~5 degrees. These fluctuations have failed the detection of the galactic light.

These fluctuations have been also found by Peterson and Kieffaber[5),6)] from the ground based photometric and photographic observations, which may not be free from the disturbances in the mesosphere such as clouds or haze. The details of the observations has been discussed elsewhere,[7)] in which it was suggested that the observed fluctuations are caused by the motions of the upper atmosphere i.e. winds, gravity waves and turbulence. The observations of such fluctuations in the OH airglow intensity will be used as a good

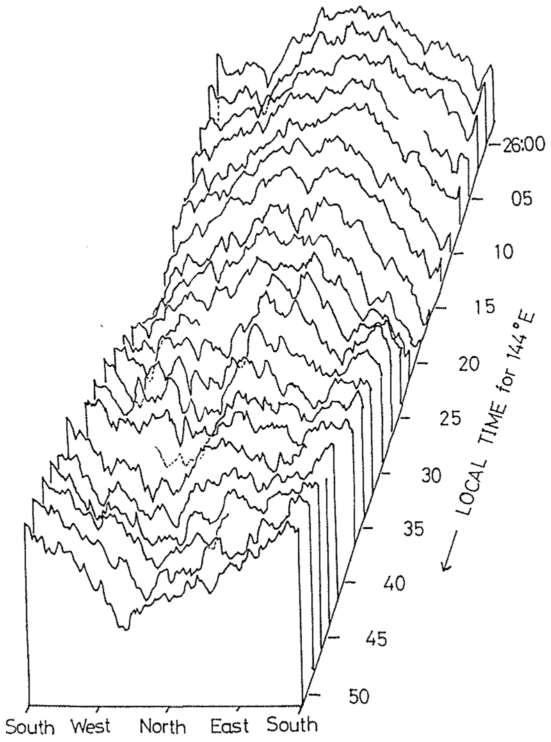

Fig. 11. Observed intensity fluctuations of the OH airglow emission during the period from 26 : 00 to 26 : 50 local time.

probe for extensive studies in space and time of the dynamical properties near the base of the thermosphere.

We thank the staff of the Sanriku Balloon Center for their kind assistance in the flight.

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