PROCEEDINGS OF SCIENCE

Evaluation of Emulsion Films Conditions on the Base of Cosmic Ray Tracks Registered in Transport Test Emulsion Films for the GRAINE2023 Experiments

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The GRAINE experiment observes cosmic gamma rays emitted from galactic central regions and pulsars. This is an experimental plan for the purpose of performing precise observations. So far, production experiments have been conducted in 2011, 2015, 2018, and 2023. In the 2023 experiment, a scaled-up balloon experiment compared to the 2018 experiment will be conducted. Along with that, there are changes such as transportation methods compared to past experiments, A transport film test was performed. A large number of nuclear emulsion plates were also developed. In this paper, I will explain the results of the transport film test and the details of the development work to efficiently develop a large number of nuclear emulsion plates.

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1. GRAINE Project

Gamma-Ray Astro-Imager with Nuclear Emulsion (GRAINE) is an experimental project for precise observation of cosmic gamma rays using a nuclear emulsion telescope with high angular resolution mounted on a balloon.

The emulsion gamma-ray telescope consists of a converter section that detects the electron pair production of gamma rays by using emulsion film stacked structures, a time stamper section that adds sub-second time information to individual tracks by using a multi-stage shifter mechanism installed downstream of the converter section, and star cameras that monitor the telescope's attitude toward the celestial coordinate during observation. The emulsion film can measure electron-pair tracks in three dimensions with sub-micron spatial resolution directly below their interaction point, and can determine the angle of incidence of the parent gamma ray with high angular resolution. It can also measure the azimuthal angle of the electron pairs for measuring the polarization of the gamma rays.

The GRAINE project aims to realize the world's largest aperture, the world's first polarization-sensitive, and the world's highest angular resolution observation of cosmic gamma rays through repeated long balloon flights using emulsion telescopes with an aperture area of 10 square meters, which can be mounted on a balloon.

2. Film Transportation Test toward GRAINE 2023 Balloon Experiment

2.1 Film Transportation Test

GRAINE 2023, the fourth balloon experiment of the GRAINE project conducted in April 2023, launched a 2.5-square-meter emulsion telescope in Alice Springs, Australia, with an aperture area 6.5 times larger than the previous one, for precision imaging of Vela pulsars and GeV-band gamma rays in the Galactic center region The objective is to obtain precise imaging of the Vela pulsar and gamma rays in the GeV band of the Galactic center region.

Since the amount of film used in this experiment is larger than in previous GRAINE experiments and it is difficult to develop the film in Australia, all the films will be returned to Japan after the balloon flight and developed using large facilities at Gifu University. This is the first time GRAINE has returned undeveloped films from overseas after an experiment. Particular attention must be paid to import/export procedures to avoid X-ray inspection at airports and customs. Prior to the real experiment, a test was conducted in October 2022, in which emulsion films were sent to the Australian site and returned to Japan via the same route as the GRAINE 2023 experiment.

The purpose of this test is to demonstrate that there are no problems with transportation. The transportation test was conducted with emulsion films and temperature logger in a cooler box, which is also used in the production experiment, as shown in the figure 1. The film was transported by air to Brisbane via Sydney Airport, the same route as for the transport of GRAINE 2023, for import customs clearance. In the transport test, it was turned around from Brisbane (the acutual transport of GRAINE 2023 will be by refrigerated truck from Brisbane to Alice Springs), cleared through export customs, and returned to Nagoya via the same route.

For the development, a special rack with spring hooks was made and used to efficiently develop the large size emulsion films shown in the figure 2. Since the four corners were pulled, it was possible to prevent problems with films touching each other even at narrow intervals.

Figure 1: Cooler box used for film transport test

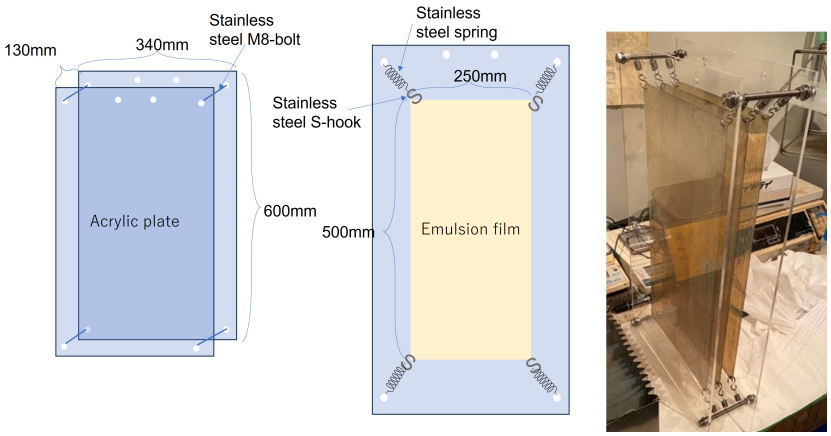

Figure 2: Film rack for development in the film transportation test

2.2 Result

The following three points were checked in this test: 1) to make sure that the emulsion films have not been X-rayed during the transportation and return process; 2) to measure the storage temperature history during the return trip to make sure that they have not been exposed to a high sound level environment for a long time; 3) to compare the quality of the nuclear plates with those stored in Nagoya University to make sure that the film quality (especially the fog density) has not been affected.

Figure 3 shows the temperature and pressure history that were read from the temperature logger after return. The films were stored in refrigerated conditions until arrival at Brisbane Airport, the outbound destination, but on the return trip, due to a procedural error by the carrier, the films were stored in a room temperature environment for four days until departure from Australia.

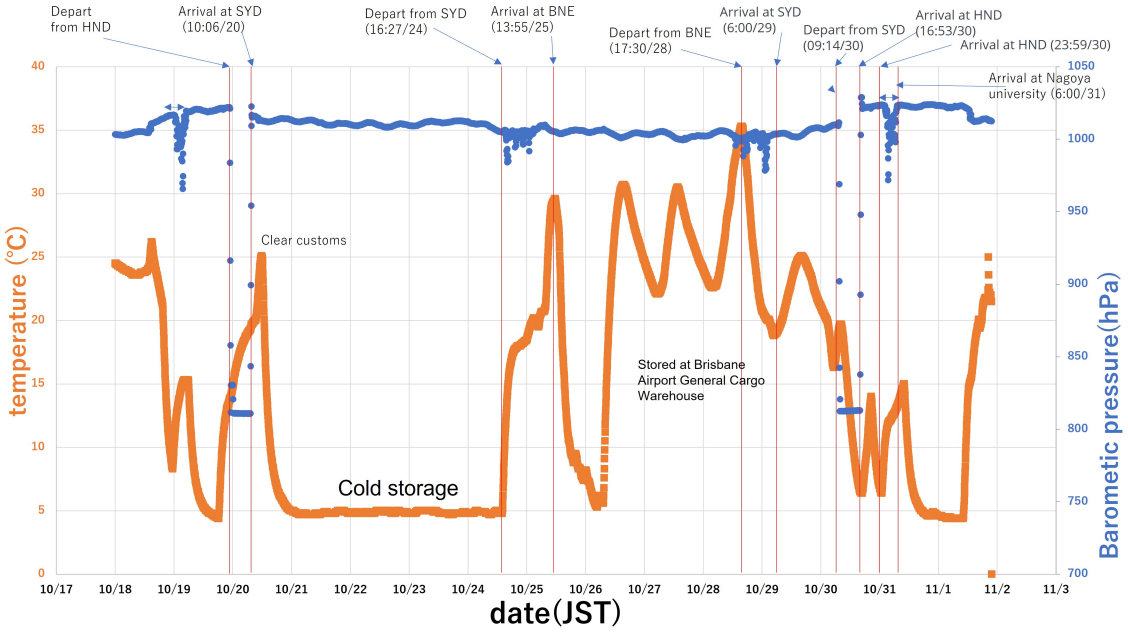

Figure 3: The temperature and pressure history in the film transportation test

As a result of microscopic observation of the films transported to Australia, it was confirmed that there was no tendency for them to be irradiated by X-rays, and that their condition was comparable to that of the films stored at Nagoya University. Next, the Fog Density (FD) was measured. We observed a randomly selected area (10 μm × 10 μm in depth 70 μm) in the emulsion layer with a microscope, confirmed that no tracks were included, and counted the number of random noize grains (fog) in that volume. Thirty locations were counted for each of the films transported to Australia and stored at Nagoya University. The results are shown in figure 4. The transport test, which was conducted assuming the actual transport route in GRAINE 2023, proved that there was no effect of noise increase in emulsion films.

3. Development of GRAINE 2023 Balloon Experiment Films

3.1 GRAINE2023 Balloon Experiment

The balloon launch of the GRAINE 2023 experiment was conducted in Alice Springs Balloon Launching Station, Australia on April 30, 2023. The 26-hour flight successfully covered the planned observations of the Vela pulsar and the Galactic center region. After the balloon flight, the instruments were successfully recovered, and all the emulsion films were returned to Japan by refrigerated truck and air transport. See reference [1–8] for details.

3.2 Set up for Development

Film development was carried out using the large-scale developing facility at the Double Hyper Nuclear Experimental Building at Gifu University. The setup is shown in figure. A 390-liter developing solution tank was placed inside a large thermostatic water tank. One 390-liter tank was used for the stopping solution and two 390-liter tanks were used for the fixing solution.

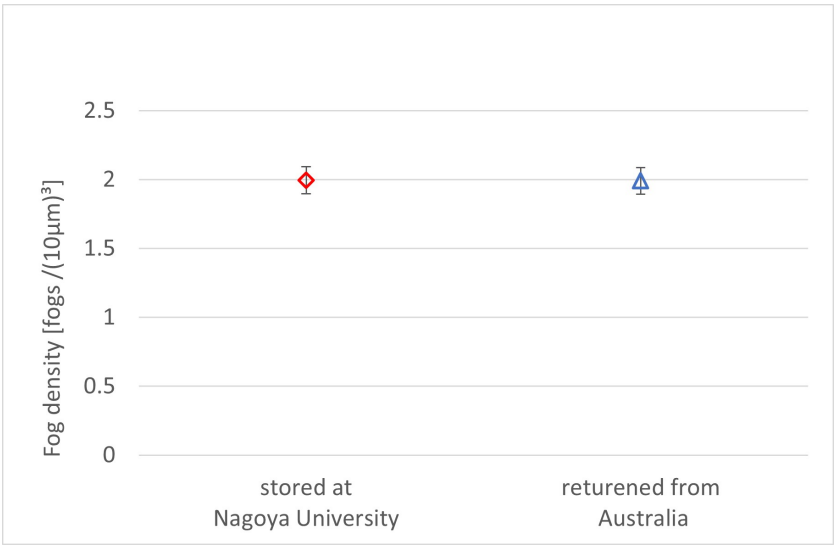

Figure 4: Measured fog densities of the films returned from Australia and stored at Nagoya University.

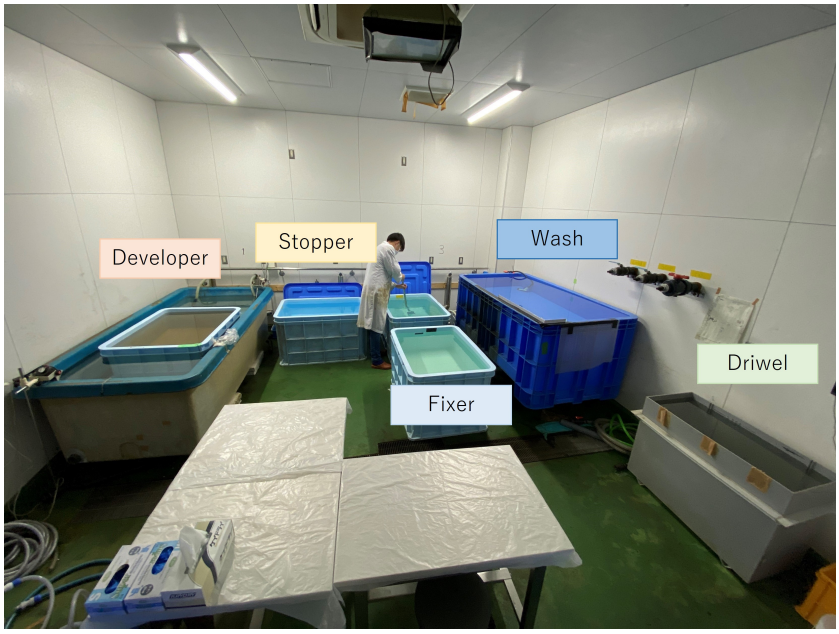

Figure 5: set up for development of GRAINE 2023 emulsion films at Gifu University

In order to develop a large amount of emuslion films efficiently, a larger-scale developing rack was fabricated based on the design of the developing rack used in the film transport test. Two of these development racks were used in one cycle, and 45 sheets were developed in one cycle, Two cycles of development yielded 90 sheets, which was enough to develop one modules of converters.

3.3 Performance of Development in GRAINE 2023

Figure 7 shows the results of converter film development at GRAINE 2023. After the films was returned, it took about one month to establish the setup for continuous development, and the

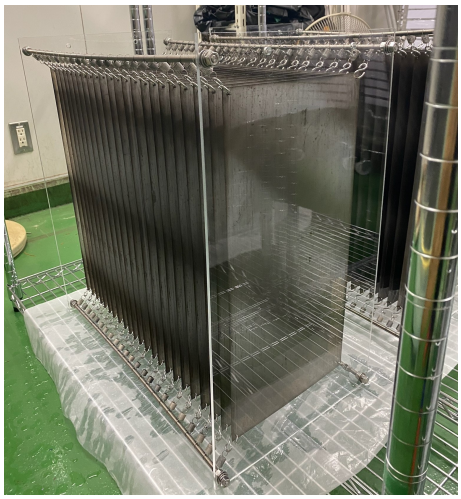

Figure 6: rack for real scale development

first converter (90 films) was developed on June 14. After the time-stamper films were developed, the remaining 19 modules of converter were developed in a stable and continuous process. Once the work process was established, the speed was increased by approximately 2.3 times compared to the development speed of the 2018 GRAINE experiment.

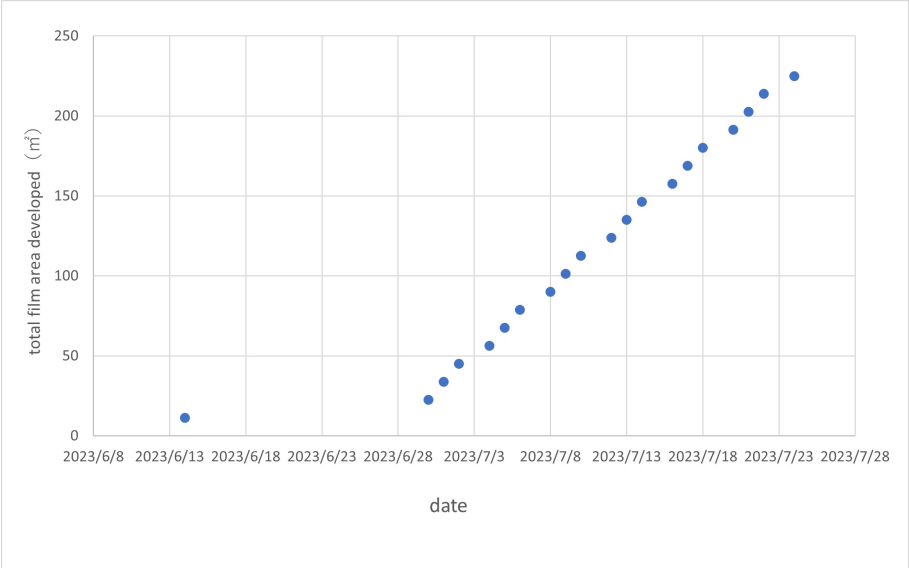

Figure 7: Result of converter film development in GRAINE 2023

4. Summary and Prospects

Preliminary tests were conducted for the export and import of film between Japan and Australia toward the GRAINE 2023 balloon experiment. Procedures to avoid X-ray inspection at airports and customs confirmed that the film could be transported back in good condition. The fog densities of

the films were evaluated and confirmed that the noise level was equivalent to that of the film stored in Japan, demonstrating that there were no problems with the transportation method used in the real process of GRAINE 2023.

The GRAINE 2023 balloon experiment was conducted on April 30, achieving a 26-hour flight. In order to develop a large amount of film reliably, new developing racks were created. Stable and continuous development work was carried out in the large developing facility at Gifu University, and the development process of all the emulsion has been completed. Data acquisition and data analysis of the developed films are starting, aiming to present high-resolution imaging results of gamma-ray sources in the GeV band.

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