PROCEEDINGS OF SCIENCE

Analyses of cosmic ray tracks registered in transport test emulsion films for the GRAINE 2023 experiments

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The GRAINE(Gamma-Ray Astro-imager with Nuclear Emulsion films) project aims to observe gamma-ray sources in the energies of sub-GeV to 10 GeV with high angular resolution. The GRAINE experiment carried out the observations of gamma ray arrival directions by using long duration balloon flights of large-area emulsion films with high angular resolution to earn the total amount of cosmic origin gamma rays, and explored unsolved problems such as the production mechanism of high-energy gamma rays at astronomical sources. Three previous flight experiments have been conducted in 2015, 2018, and 2023. In the previous experiment (2018), the balloon-borne experiment(GRAINE2018) with an aperture area of 0.38 m^2 and a flight time of 17 hours was conducted in Australia, and the imaging of Vela pulsar was successfully obtained. The current experiment (GRAINE2023) has a larger scale than the previous experiment(GRAINE2018), such as an aperture area of 5 m^2 and a flight duration of 26 hours. The GRAINE2023 balloon flight experiment took off on April 30, 2023, at 6:00 a.m. Japan standard time, and after 26 hours of flight, landed at a point 220 km south of Longreach, Queensland, Australia. After the successful recovery, chemical developing of nuclear emulsion films were completed. In this presentation, the transport test of nuclear emulsion films for GRAINE2023 balloon flight are going to be reported as well as the GRAINE2023 experiment and the HTS(hyper Track Selector) .

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1. Introduction

The most distant objects in the universe currently observed are gamma-ray bursts whose phenomena makes bright signals for only a few milliseconds to a few hundred seconds. The latest observations show that the source of gamma-ray bursts are jet produced by the center of distant galaxies, the collapse of massive stars or the merging of neutron stars and black holes in the cosmological distance. And one of the known sources of high energy gamma rays are the pulsars which are rotating neutron star with high magnetic field strength, such as the Vela pulsar and the Crab nebula. The mechanism of gamma ray production at the sources are still unresolved. The unknow information were being revealed by the Fermi Gamma-ray Space Telescope which was launched in 2008. However, these observations of gamma rays at tens to hundreds of MeV are difficult, and the angular resolution is several orders of magnitude worse to understand the detail feature of gamma-ray sources in this energy range. The GRAINE (Gamma-Ray Astro-Imager With Nuclear Emulsion films)[1–3] is a project that aims to observe and analyze cosmic gamma rays in high detail using nuclear emulsion plates as detectors (Figure. 1). In GRAIN2013 experiment, we carried out balloon flight in Australia and the nuclear emulsion films needs to be brought back to Japan to be developed. In this report, we analyze the transportation method of nuclear emulsion films and evaluate the affect of X-rays inspections at the airport and noise tracks and grains due to the accumulation of cosmic ray background tracks during the transportation.

Figure 1: GRAINE2023 Flights in Australia

2. Transport film test

In GRAINE2023 experiment[4–6], we are going to transport nuclear emulsion films from Japan to Australia by air cargo and from Australia to Japan after the completion of balloon flight.

We have to handle the amount of films which is 6.5 times larger than in GRAINE2018. The film needs to be developed in Japan instead of in Australia(GRAINE2018). The transportation test was conducted in October-November 2022, by using the expected transportation path as for the GRAINE2023 nuclear emulsion films. The method of transportation was to prepare two same set of emulsion chambers with several emulsion films stacked on top of each other. We deployed each set of chambers vertically and the other horizontally to the earth ground (Figure. 2) . Those chambers were stored in cooler boxes and the boxes were transported by air cargo and surface-truck from Nagoya University to Alice Springs, Australia. After transporting, transport film test are carried out with the following steps[6]: (1)checking to see that the film has not been exposed to X-rays for baggage inspection, (2)checking the temperature and barometric pressure history recorded in data-logger, (3)storing the control chambers of the same nuclear emulsion films as the transported ones at the Nagoya university , and then (4)sending the film transported to and from Australia and . After the film was returned from Australia, the transport film and the control film were developed simultaneously in the same chemical conditions, and the track data were analyzed by the High Speed Track Detection System (HTS)[4].

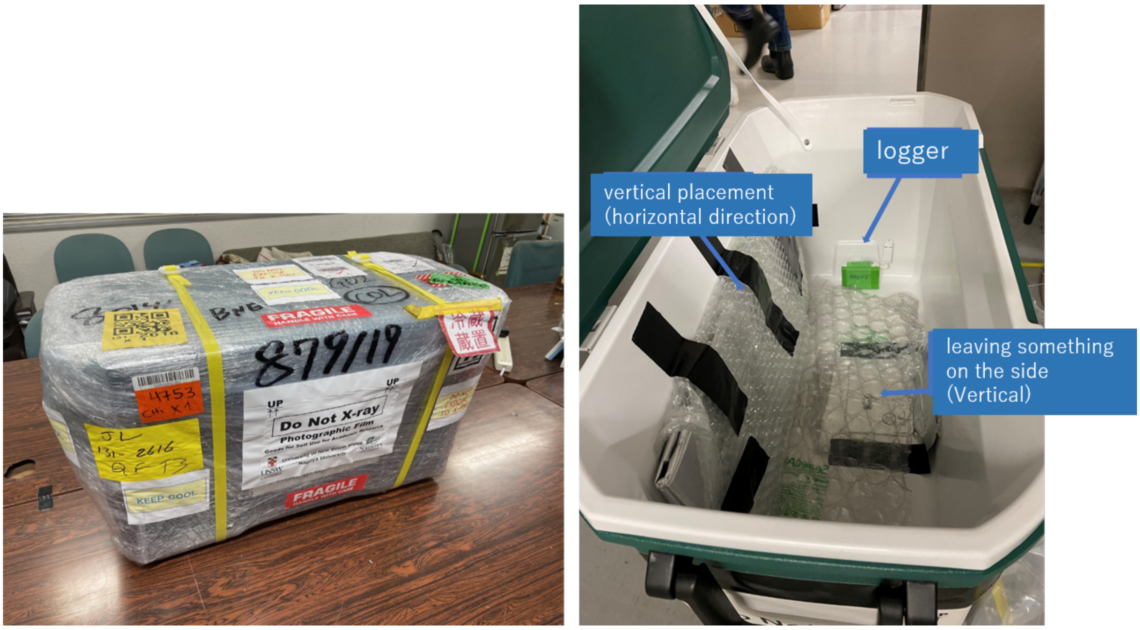

Figure 2: A cooler box with a chamber to transport to Australia and a logger to measure air pressure and temperature history.

3. Analysis of observation data

After acquiring and binarizing a tomographic image of the emulsion layer, the each image is shifted and the amount of vertically aligned hit pixels added up (pulse height) is used to determine the trace-like characteristics. This enables a three-dimensional search for linear tracks that penetrate the nuclear emulsion film at various angles. The track-selection speed are increased dramatically and the current system(Hyper Track Selector (HTS)(figure. 3) is capable of reading 4700 cm^2/h. A film placed on the operating stage is read by an objective lens with a wide field of view of 5 mm x 5 mm, and the image is processed by 36 PC cluster to recognize the tracks. The next-generation HTS2 (2021) is under development, which is expected to improve the reading speed by a factor of 5 from the HTS and to be analyze the GRAINE2023 nuclear emulsion films. These developments have made it possible to perform experiments such as reading the entire volume of a large-area nuclear emulsion films.

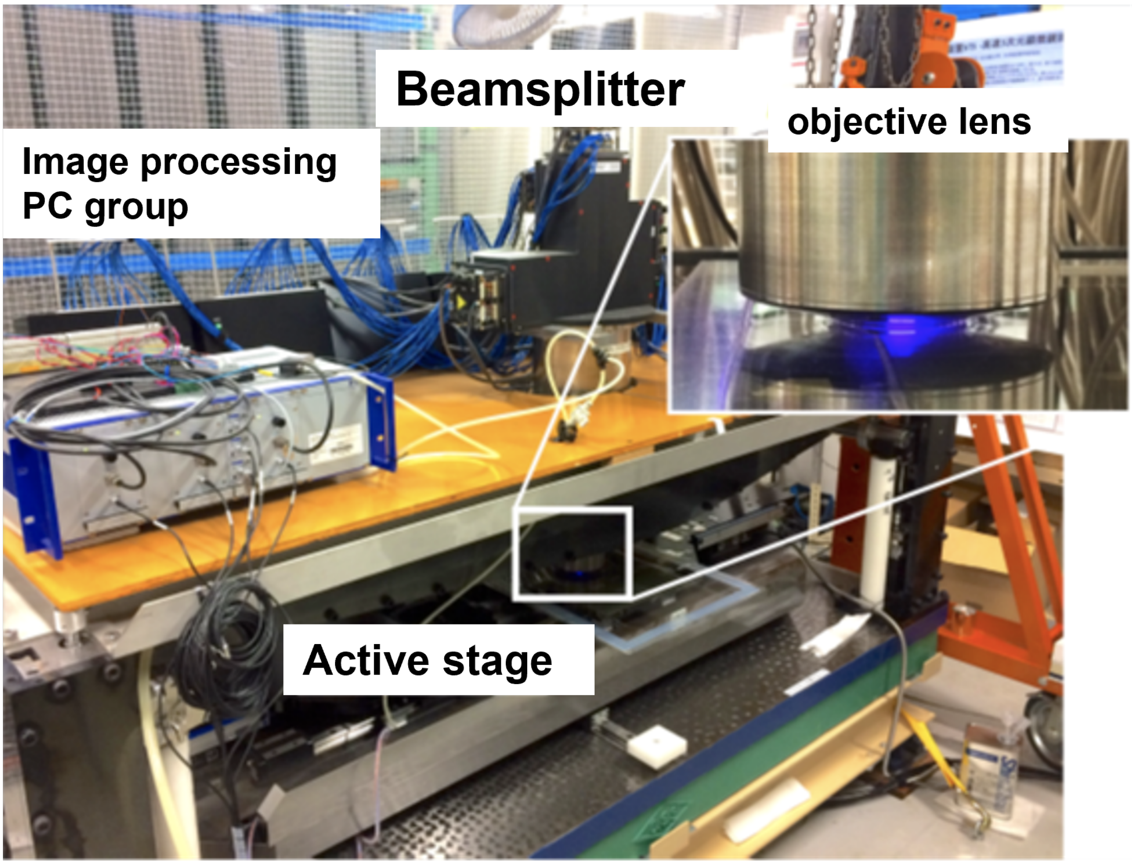

Figure 3: Hyper Track Selector(HTS)

4. Evaluation of angle in tracking process

We have three types of tracks in double layered nuclear emulsion films. The micro-tracks are defined in the both single layer of nuclear emulsion films, and the base-tracks are done as the connection of each micro-track of which inclinations and extrapolated positions are quite similar. We connect micro-tracks with some connection criteria and obtain base-tracks in each film. The base-tracks are consist of two micro-tracks. Finally we define the linkage (linklet-tracks) of base-tracks in between two films which are identified as he base track connected to the top and bottom two films based on the distribution of both position and angular alignment. We analyze the angle distribution of the cosmic rays on the film (zenith angle) and the pulse height which indicates how many silver particles (grains) that make up the track were connected. the linklet-tracks are the result of identifying the base tracks connected to the two films. We confirm that the tracks are connected in a straight line in multiple films.

In order to estimate the affect of background cosmic ray tracks, the angular distributions obtained from these two operations(transportation-films and control-films in vertical placement and horizontal placement), are compared. Figure. 4 shows the base-track distribution on the Australian

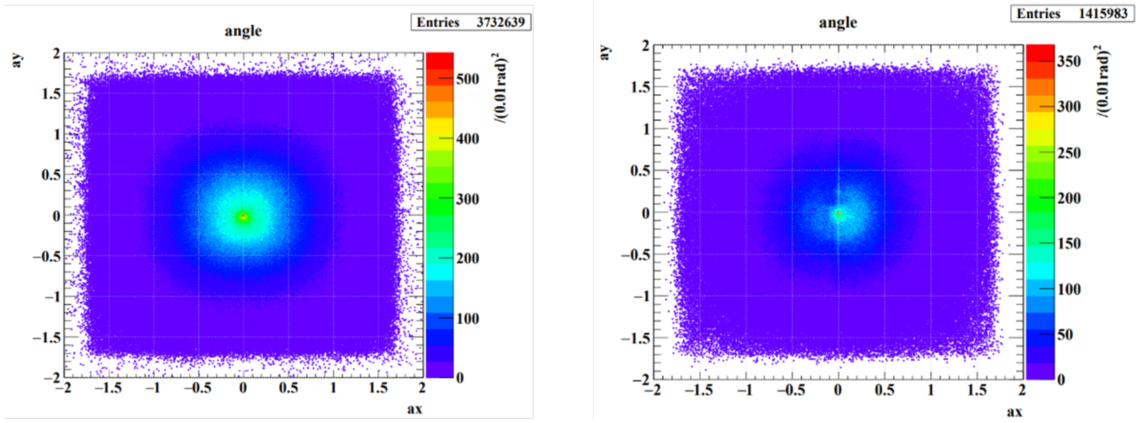

Figure 4: Angular distributions of base-tracks in two flat films(left: Australia transportation-films, right: control films storing at Nagoya University)

transportation film on the left and the control-film stored on the ground on the right as a function of the projected tangential angle (ax and ay). The difference between these two is the total amount of cosmic rays accumulated in the film. On the left in the same figure(transportation-horizontal case), cosmic ray background tracks are distributed as a cosine type around the center, which means the zenith angle is equal to zero. Its peak position is seen at (ax, ay)=0. In the right panel, the peak is less intense than in the left panel, but there is some obstacle at ax less than 1, so that the entry shape is asymmetrical. To minimize base-track ambiguity of track-recognition,a linklet-tracks were used. The cosmic ray arrival distribution in both transportation-film and control film are shown in figure 5. The shape of each distributions are affected by the HTS capability in the inclination angle of tracks ($\tan\theta \sim 1.6$).

The angular distribution of the vertical placement films in both transportation and control films are shown in figure 6 The double peak features came from the slight tilt angle of vertical placement. Cosmic ray mostly arrived from the top of atmosphere vertically and this tilt angle(around 5 degree) make these feature because almost all cosmic ray penetrate emulsion films parallel to the emulsion films.

In Figure 7, we compare the angular distributions of 4 chambers(Transport-horizontal:TH, Transport-vertical:TV, Control-horizontal:CH and Control-vertical:CV). In this figure, we restricted the ax value to less than 0.2 because of noise level. In the TH chamber, the total number of cosmic ray tracks is greatest in the 4 chambers due to the air cargo flight. On the other hand, the CV chamber has the smallest number, because the storage of CV is the first floor of 4 stories buildings. In the GRAINE2023 project, incident angles $\tan\theta < 1.0$ would be the most important objectives. In the TV chamber, cosmic ray tracks were suppressed much more than TH in the objective zenith angle regions.

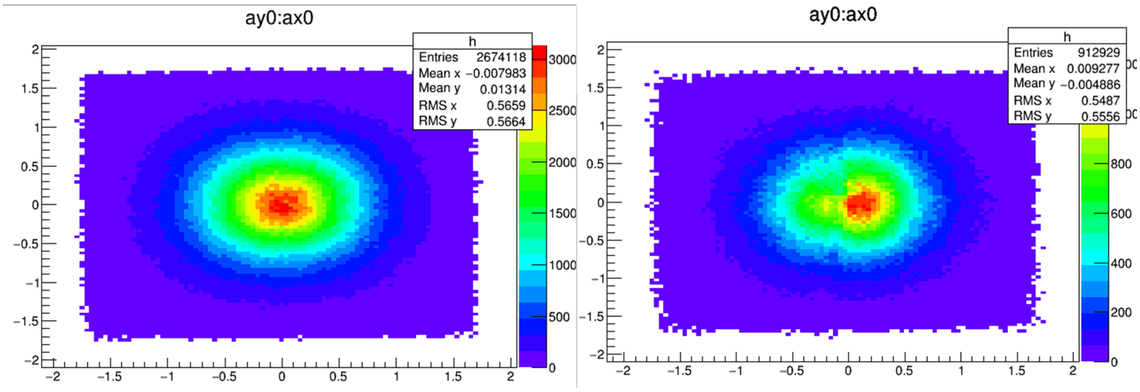

Figure 5: Angular distributions of linklet-tracks in two flat films (left: Australia transportation-films, right: control films storing at Nagoya University)

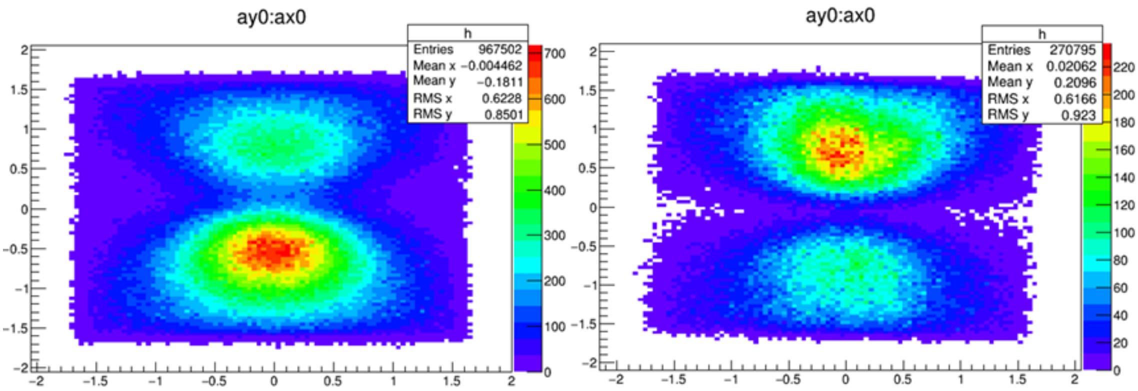

Figure 6: Angular distributions of linklet-tracks in two vertical films (left: Australia transportation-films, right: control films storing at Nagoya University)

5. Summary and Conclusion

The transportation test of nuclear emulsion films was performed for the GRAIN2023 balloon experiment. In this test, we have examined the environmental effect of transportation and storage of nuclear emulsion as well as X-ray baggage inspection. We also minimize the accumulation of cosmic ray background tracks during the transportation in the air cargo by deploying the nuclear emulsion plates vertically to the earth surface. To perform the high quality image analysis in HTS in the zenith angle less than 1.0, the vertical placement of nuclear emulsion chambers in the transportation is found to be very effective in the angle range $\tan\theta < 1.0$. Currently, the nuclear emulsion films used in the GRAINE2023 experiment have been developed at the facility of Gifu University. The data analysis has started.

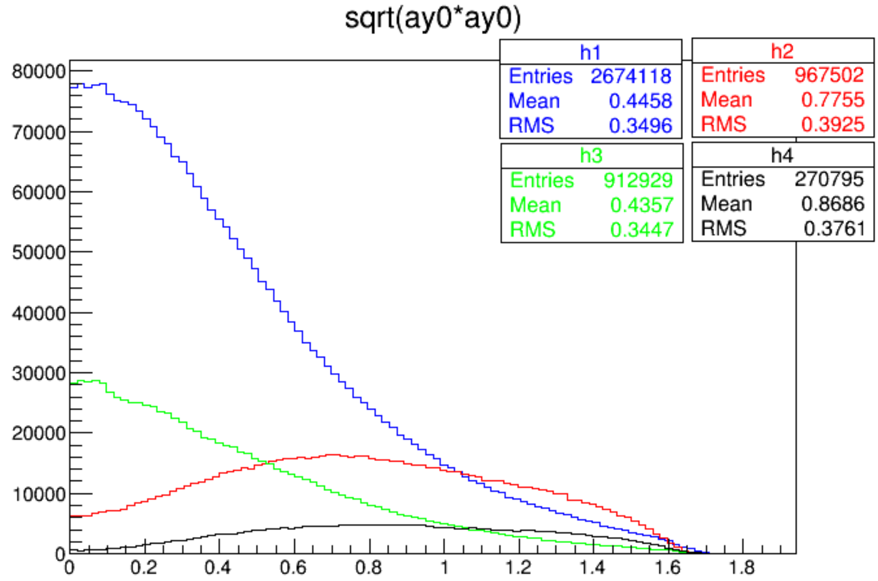

Figure 7: Angular distributions of 4 chambers of linklet-tracks(h1,h2,h3 and h4 indicate Transport-horizontal:TH, Transport-vertical:TV, Control-horizontal:CH and Control-vertical:CV, respectively)

References

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