PROCEEDINGS OF SCIENCE

# Recognition of cosmic ray nuclear tracks in the GRAINE2018 emulsion films with machine learning approach

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The GRAINE projects are going to perform the balloon flight with high angular resolution imaging technology by nuclear emulsion films, in April, 2023 at Alice Springs, Australia to explore the nature of gamma-ray emission of high energy stellar object such as Vela pulsar and the galactic center of milky way. The tracks of cosmic ray nuclei have already registered in the nuclear emulsion films exposed in the previous balloon flight of the GRAINE2018 project carried out at the Australia. The collection factor of cosmic ray nuclei in GRAINE2023 flight could be about 12 times larger than that of the GRAINE2018. We have been developing the image analysis application for track recognition of cosmic ray nuclei with a machine learning technology for the nuclear emulsion films. We are going to report the status of our approaches.

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## 1. Introduction

The nuclear emulsion technologies including new chemical characteristics of nuclear emulsion gel production and chemical development processes, active detecting capability of nuclear emulsion chambers with the attitude monitoring of balloon gondola by using star cameras system have been developed and installed in the GRAINE(Gamma Ray Astro-Imager with Nuclear Emulsion) experiments in the balloon flight at Alice Springs, Australia, 2015[1] and 2018[2][4][3]. The charged tracks identifying system within a wide zenith angle allowances have also been implemented as the hyper track selector (HTS[5] and HTS2). These recent technologies have enable the GRAINE experiments to perform the cosmic ray gamma ray observation such as Vela pulsar in 10 MeV ~ 100 GeV energies with a precise angular resolutions.

The GRAINE experiments have been carried out large area exposure(~ 5m$^2$) of nuclear emulsion films in the end of April, 2023 at Alice Springs ,of which duration was about 24 hours. The GRAINE instruments was developed to measure the electron pairs created converted by gamma rays in the emulsion chambers. In the GRAINE experiments, the tracks of cosmic ray nuclei(CRN) of which charges are above protons, have been omitted in the following track analysis procedures due to their relative high ionization signals. On the other hand, to detect and measure the chemical composition of heavier cosmic ray nuclei, relative high ionization signals have to be used in the image analysis of nuclear emulsion films. In this report, we introduce to the capability of desensitization of nuclear emulsion films used in GRAINE2018 for identifying cosmic ray nuclei(CNO). We have also described the training data for machine learning system to identify tracks of cosmic ray nuclei in nuclear emulsion films by using the maximum contrast method.

**Figure 1:** The Gondola of GRAINE2018 balloon-borne emulsion chamber.

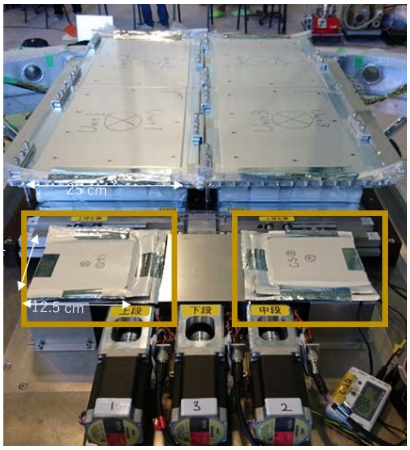


**Figure 2:** The two emulsion chambers for CRN detection deployed on the main control system, which were indicated with color rectangles.

## 2. Results of GRIANE2018 flight with desensitized nuclear emulsion films

In GRAINE2018 flight, the balloon-borne experiment with a 0.38 m$^2$ aperture shown in figure 1 had been carried out to examine the performance to detect a know gamma-ray source, Vela Pulsar. The total level flight duration at 35-38 km altitude was 15 hour among 17.4 hour flight. We deployed two sets of the CRN chambers with desensitized nuclear emulsion films[6] in the gondola shown in figure 2. The size of chamber was 10 × 10 cm$^2$ and 8mm thickness with 15 nuclear emulsion films of various sensitivities and one CR-39 plate per one chamber shown in figure 2

We have developed the desensitized nuclear emulsion films by adding rhodium compounds of some densities in producing nuclear emulsion gels. We poured these gels to plastic base films and constructed the nuclear emulsion chambers with normal sensitivity nuclear emulsion films. We have also examined the performance of desensitized nuclear emulsion film with HIMAC beam facility. In figure-3, the ionization of carbon beam behaved like that of helium beams in normal sensitivity nuclear emulsions.

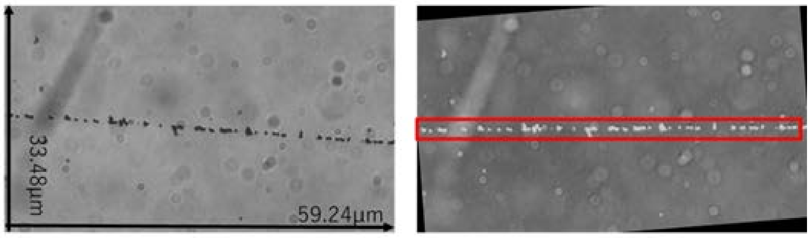


**Figure 3:** Practical effect of rhodium compound adding to identify Carbon tracks in RH50 emulsion films.

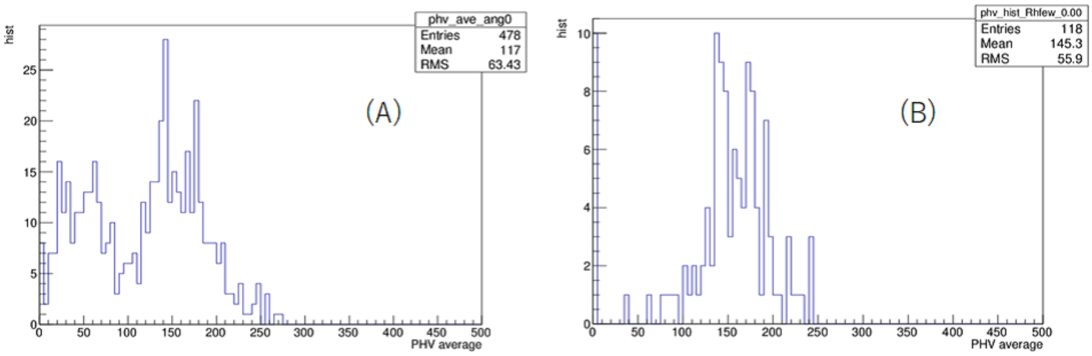


**Figure 4:** The PHV distribution for each zenith angle region : $\tan\theta < 0.25$. (A):RH25(low density) films solely and (B): RH25(low density) and RH50(high density) films coincidence required. The horizontal axes still represent the mean PHV values obtained from three RH25 emulsion films.

To detect CRN with desensitized films, we have analyzed the volume pulse height(PHV) signals, which defined and calculated by HTS system. The PHV indicated the amount of ionization energy losses of CRNs. In Figure4, we compared track phv signal distributions of two rhodium compound densities added in emulsion gels for the track zenith angle less than 0.25.

We concluded in GRAINE2018 flight, that the desensitizing of nuclear emulsion films was very useful to detect high-Z CRNs. Another possibility was to trace the particle trajectory by connecting maximum contrast grains.

## 3. CRN track search in the Super-JACEE and the GRAINE2018 films for training data

### 3.1 Method

To identify CRN tracks in normal nuclear emulsion films instead of desensitized ones,we implement multi-focus image fusion methods for 3-dimensional CRN track images. The arrival directions of cosmic rays are uniform respect to emulsion film plane, and it is difficult to handle CRN tracks as 3 dimensional image sequence, because we do not have the entire zenith angle tracks in our data sample. In order to handle CRN track images in 2 dimensional coordinate, we reduce the vertical coordinate to emulsion plane. We use composite image method to make 2 dimensional CRN image with relative low magnification of our microscope system. To get a composite image from sequential images, various approaches such as image gradient filter, Laplacian operator, wavelet descriptor, statistical feature method, DCT , FFT as well as maximum contrast method[7] were examined. We determined the maximum contrast method within square-micrometer area. In Figure-5, left panel shows a microscope image of 636 image sequence obtained by 20 magnification objective lens. The rectangle in left panel indicate typical analysis area size. The right panel shows the evaluated contrast value in each image sequence. The contrast peak value is located around the image sequence number 230. In this example, we determined the pixel value and image sequence number. We perform the same analysis for the entire image area, then we can get composite images.

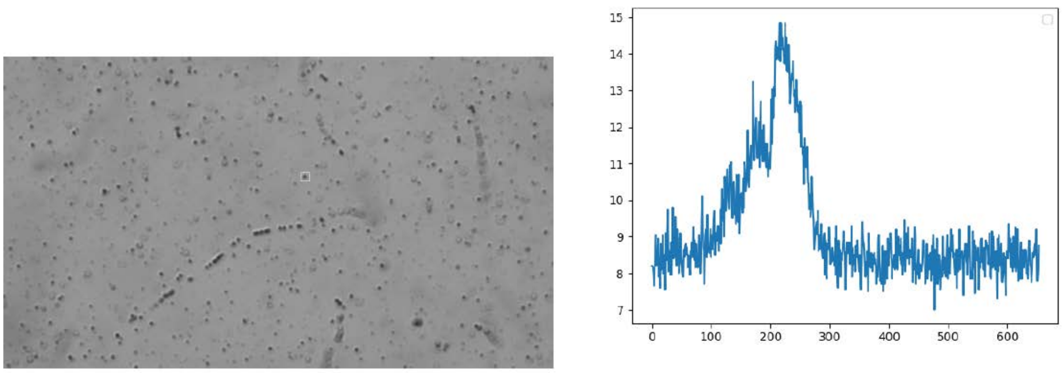


**Figure 5:** Result from maximum contrast method. Left panel shows one image obtained by 20 magnification microscope. The contrast distribution of the rectangle area in the right panel. The contrast value has a peak at around the image sequence number 230.

### 3.2 CRN images from Super-JACEE and GRAINE2018

In Sept. 27 1995, JACEE(Japanese-American Cooperative Emulsion Experiment) carried out the balloon flight of nuclear emulsion chamber installed in the super conducting magnet at Fort

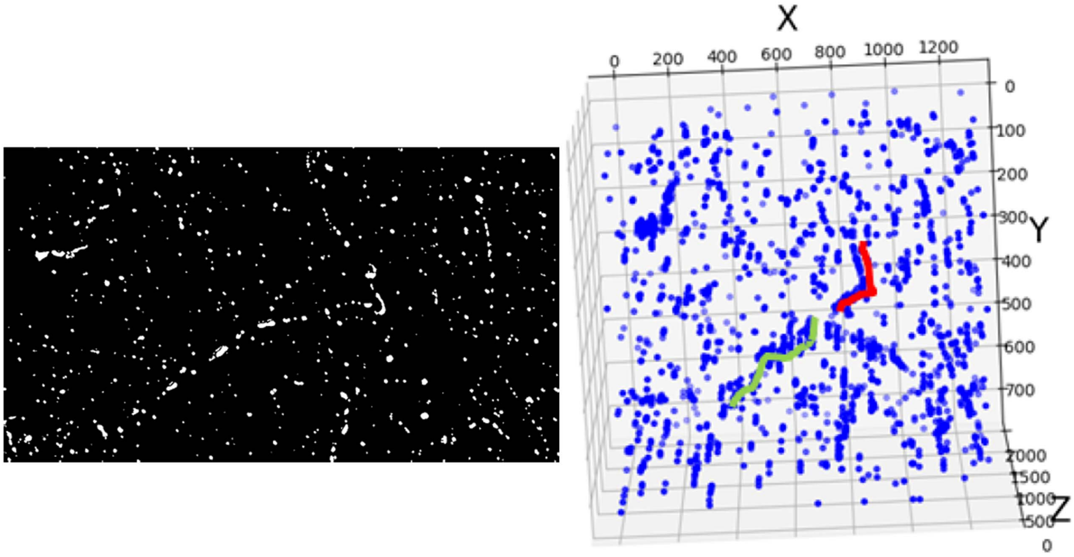


**Figure 6:** 3 dimensional trajectory of electron obtained by maximum contrast method. The depth coordinate values were represented by image sequence numbers.

Sumner, USA[8]. In Super-JACEE experiments, emulsion films of $40\times50cm^2$ were exposed. We have used these emulsion films as well as those in GRAINE2018.

## 4. summary and prospects

We promote the CRN track analysis capability in the GRAINE experiments by using multi-focus image fusion method such as maximum contrast method as well as desensitizing of nuclear emulsion films. To apply the machine learning system for identifying tracks of cosmic ray nuclei in the nuclear emulsion films, we have to obtain more statistics of real cosmic ray nuclei images as training data. We also need simulated track images to make up for the statistical lack of real images.

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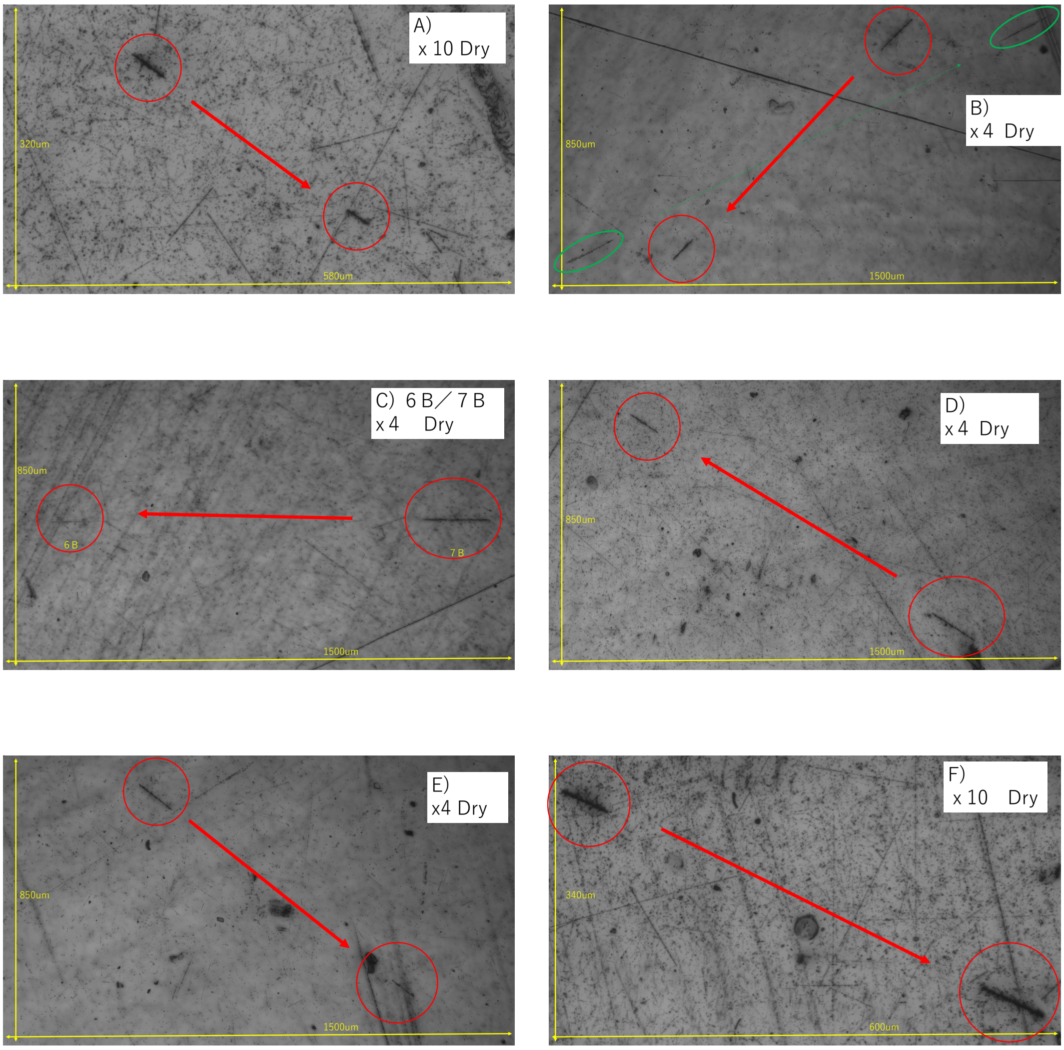


**Figure 7:** CRN tracks in Super-JACEE emulsion plates. By compositing track image in both emulsion layers, CRN track lays in 2 dimensional image.In the panel B), different sensitivity nuclear emulsion were used.

and was also carried out by the joint research program of the Institute of Materials and Systems for Sustainability(IMaSS), Nagoya University.

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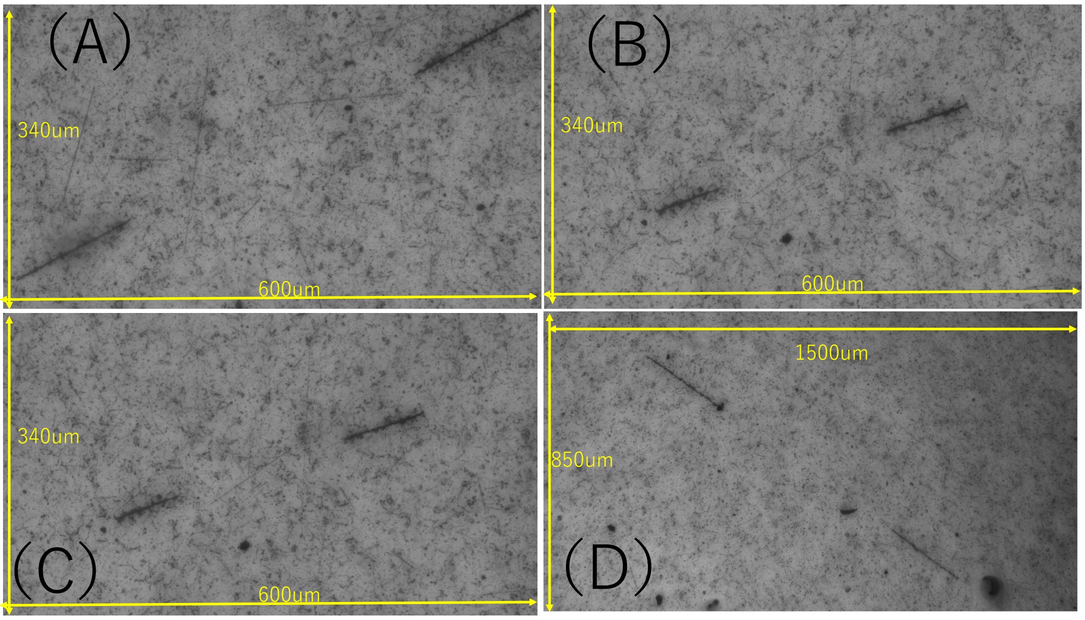


**Figure 8:** 4 examples of CRN tracks registered in GRIANE2018 balloon flight.


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