Identification of the tracks of heavy nuclei with machine learning method in the GRAINE 2023 balloon-borne experiment

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Introduction

The GRAINE (Gamma-Ray Astro-Imager with Nuclear Emulsion) collaboration [1] has constructed a nuclear-emulsion gamma-ray telescope with a time stamping system for charged particles using nuclear emulsion film shifter and an altitude monitoring system using three-star cameras synchronized with GPS. And a 27-hour balloon flight on 30 April 2023 from Alice Springs, Australia, with a 2.5 m^2 aperture (GRAINE2023) had targeted the precise imaging of the Vela pulsar, the Galactic Center and galactic diffuse emissions. This large aperture and duration of GRAINE2023 also enabled observations of cosmic-ray nuclei.

To explore the origin of cosmic ray heavy nuclei, we develop image-analysis methods that efficiently detect "thick tracks" such as cosmic ray nuclei tracks, implement full-field nuclear emulsion film scanning with a microscope and infer track attributes to identify particle charge$(Z/\beta)^2$ via the range spectrum of knock-on electrons.

This report presents the scanning framework and charge-identification techniques applied to the GRAINE 2023 data.

Experimental Procedures and Results

We applied machine learning (ML) algorithm (such as Faster R-CNN) to nuclear-emulsion images of the GRAINE2023 flight in order to automatically detect cosmic-ray heavy nuclei tracks. A candidate was accepted only when pair track was found on both sides of nuclear emulsion films. For charge identification, we evaluate the transverse spread of charged tracks relative to the track direction, due to its $(Z/\beta)^2$ dependence (β=v/c) as shown in figure 1. The ML model was trained on about 7,600 eye-scanned tracks and evaluated on about 6,000 unseen images. Figure 2 shows correctly recognized both-sided tracks with confidence scores. Without any score threshold, detection efficiency and purity were about 98% and about 23% (efficiency: fraction of labeled tracks detected, purity: fraction of detections that are true), respectively. With a score threshold of 0.5, the efficiency and purity were 95% and 29% respectively, and increasing the threshold to 1.0 reduces the efficiency to about 64% while improving the purity to about 51%.

Currently, we are studying methods to improve purity based on the recognition outputs and to derive results from analysis of the recognized track images. Finally, we are going to present elemental composition of cosmic ray heavy nuclei so far.

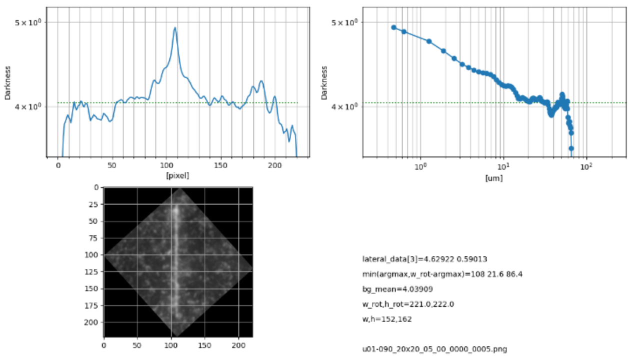

Fig1. Screenshot of the latest track-profile analysis results

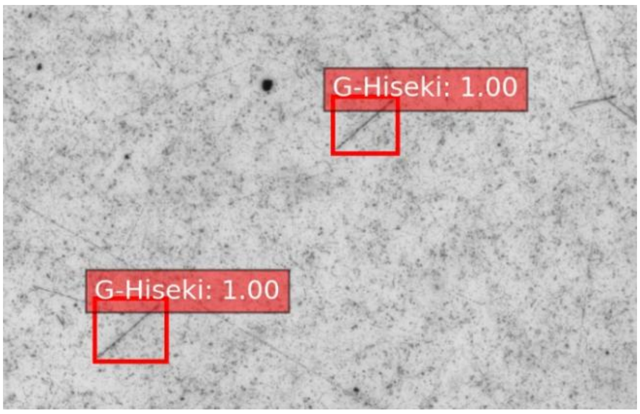

Fig2. Results of Paired Nuclear-Track Detection on Unseen Images

References

[1] S. Takahashi et al., Prog. Theor. Exp. Phys. 2016 (2016) 073F01, H. Rokujo et al. Prog. Theor. Exp. Phys. 2018 (2018) 063H01