PROCEEDINGS OF SCIENCE
ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany
37th International Cosmic Ray Conference 12–23 July 2021

PoS(ICRC2021)654

GRAINE precise γ-ray observations: latest results on 2018 balloon-borne experiment and prospects on next/future scientific experiments

Satoru Takahashi,[a,*] Shigeki Aoki,[a] Takashi Azuma,[a] Hirotaka Hayashi,[b] Atsushi Iyono,[c] Ayaka Karasuno,[a] Takumi Kato,[a] Kohichi Kodama,[d] Ryosuke Komatani,[b] Masahiro Komatsu,[b] Masahiro Komiyama,[b] Kenji Kuretsubo,[a] Toshitsugu Marushima,[a] Syota Matsuda,[a] Kunihiro Morishima,[b] Misaki Morishita,[b] Naotaka Naganawa,[b] Mitsuhiro Nakamura,[b] Motoya Nakamura,[a] Takafumi Nakamura,[a] Yuya Nakamura,[b] Noboru Nakano,[b] Toshiyuki Nakano,[b] Kazuma Nakazawa,[e] Akira Nishio,[b] Miyuki Oda,[a] Hiroki Rokujo,[b] Osamu Sato,[b] Kou Sugimura,[b] Atsumu Suzuki,[a] Mayu Torii,[b] Ikuya Usuda,[b] Saya Yamamoto,[b] Mayu Yamashita[a] and Masahiro Yoshimoto[e]

[a] *Kobe University, Kobe 657-8501, Japan*
[b] *Nagoya University, Nagoya 464-8602, Japan*
[c] *Okayama University of Science, Okayama 700-0005, Japan*
[d] *Aichi University of Education, Kariya 448-8542, Japan*
[e] *Gifu University, Gifu 501-1193, Japan*
E-mail: satoru@radix.h.kobe-u.ac.jp

[*] Presenter

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

We are developing a GRAINE project, 10 MeV – 100 GeV cosmic γ-ray observations with a precise (0.08 degree @ 1 – 2 GeV) and polarization sensitive large-aperture-area (~10 m^2) emulsion telescope repeated long duration balloon flights. We demonstrated a feasibility and performance of the balloon-borne emulsion γ-ray telescope experiment with various test experiments and developments on the ground and balloon-borne experiments in 2011 and 2015. In 2018, a balloon-borne experiment was performed with a 0.38 m^2 aperture area and 17.4 hour flight duration in Australia to demonstrate an overall performance of the telescope with a detection and imaging of a known γ-ray source, Vela pulsar. By the flight data analysis, we achieved a firm detection and highest imaging for the Vela pulsar and established the emulsion γ-ray telescope with a highest angular resolution in the γ-ray telescopes in the energy region. Based on the experiences and achievements, we aim to start scientific observations expanding an aperture area and flight duration repeated balloon flights. In 2023, we have a plan of two balloon-borne experiments in Australia by JAXA Scientific Ballooning with a 2.5 m^2 aperture area and a flight duration above 15 hours aiming, e.g., to observe Galactic Centre region with a highest imaging resolution. An overview and status of the GRAINE project, especially the latest results on the 2018 balloon-borne experiment and the prospects on the next/future scientific experiments are presented.

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

PoS(ICRC2021)654

1. Introduction and 2018 balloon-borne experiment

Cosmic high-energy γ-rays provide direct insight into extreme phenomena in the universe. By detecting a begining of an electron pair created by a γ-ray with a nuclear emulsion, excellent angular resolution for the γ-ray and to be sensitive to the γ-ray polarization can be achieved. We are developing a γ-ray telescope consisting of nuclear emulsions, aiming for precise observations of cosmic γ-rays by repeating long duration balloon flights, called this project as GRAINE (Gamma-Ray Astro-Imager with Nuclear Emulsion).

Up to now, by various developments and test experiments on the ground, and balloon-borne experiments in 2011 and 2015, we demonstrated the feasibility of balloon-borne emulsion γ-ray telescope experiment. In the 2018 balloon-borne experiment (JAXA Scientific Ballooning in Australia, aperture area of 3780 cm^2, total flight duration of 17.4 hours) realizing a significant improvement of the telescope (a total of 5 times for effective area $\times$ time expansion and background event reduction compared with the 2015 balloon-borne experiment), we aim to demonstrate the comprehensive performance of the telescope by detecting the Vela pulsar, which is a known bright γ-ray source. For the 2018 balloon-borne experiment, we achieved various developments, improvements, and preparations, then successfully performed the 2018 balloon-borne experiment. After successfully completing the development of the emulsion films in Australia (by ourselves at the University of Sydney), we brought the emulsion films and data storage disk back to Japan for the flight data analysis.

2. Flight data analysis

γ-ray event detection processing in the emulsion film stacked γ-ray converter, track time assignment processing in the multi-stage shifting timestamper, telescope attitude determination processing in the star camera attitude monitor, and data processing that integrates them, all data processing have been performed over the course of a year. In addition, efficiency improvement by picking up missed events (statistics ~20% increase), background event rejection by identifying cosmic ray-induced background events (background events ~50% reduction), and detailed understanding of detector axis alignment (<~0.1 degrees), significant improvements have been performed for the flight data. Then, we achieved a firm detection of the Vela Pulsar (>80 MeV) and obtained a spread of 0.51 degrees (Fig. 1). This means that the point source spread in radius is 6.3 times higher and the imaging resolution in solid angle is 39 times higher than that of the conventional gamma-ray telescope. We have achieved the world's highest imaging resolution of the Vela Pulsar and established the emulsion γ-ray telescope that achieves the world's highest angular resolution.

We have also searched for Galactic diffuse emission. By modeling the background distribution based on the atmospheric γ-ray east-west effect data described later and subtracting it from the observation data, the emission was indicated on the galactic plane region (-5 <galactic latitude [degree] <5) (Fig. 2). The indicated intensity was compatible with previous measurements. In the next and subsequent balloon-borne experiments, we aim to observe the intricate Galactic Centre region (3 times or more intense) with a larger amount of exposure (area $\times$ time) with the world's highest angular resolution.

PoS(ICRC2021)654

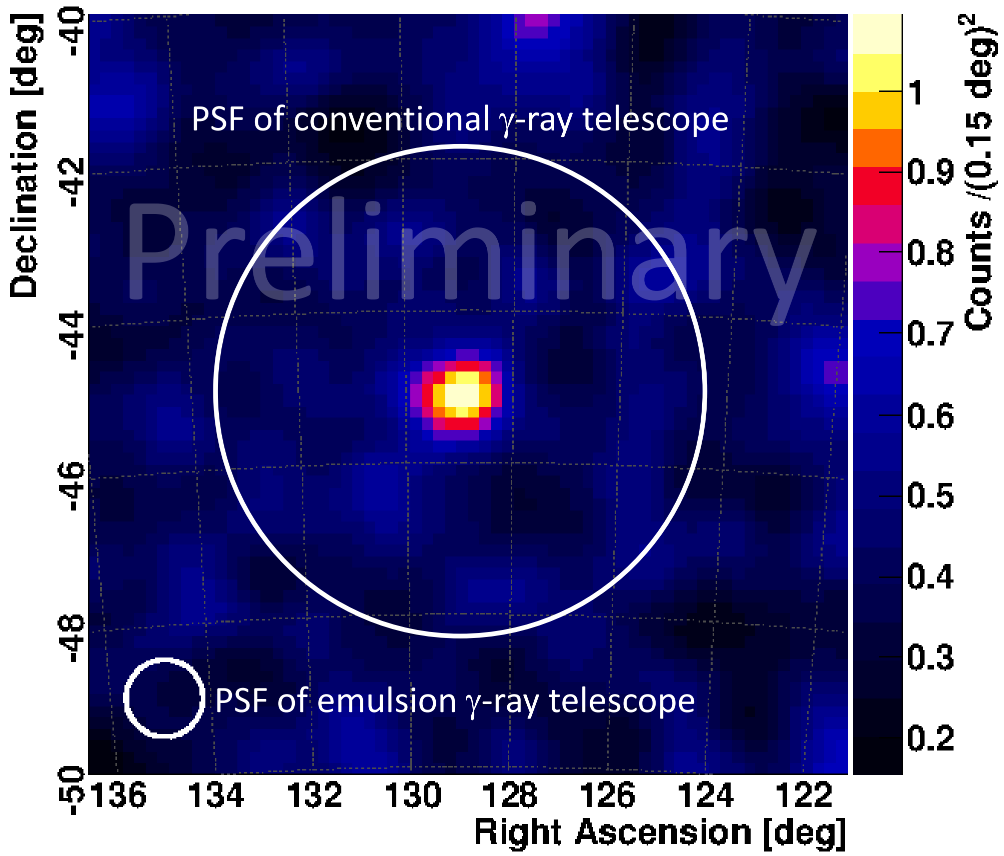

Figure 1: Smoothed count map for energies above 80 MeV in equatorial coordinates (J2000) centred on the Vela pulsar. The white circle at bottom left represents the point-spread function (68% containment radius).

We have also measured atmospheric γ-rays to understand major background events and detector responses. Especially, the east-west effect of atmospheric γ-rays at balloon altitude was observed for the first time in the world. In addition, we have developed atmospheric γ-ray physics including comparison with atmospheric neutrino flux calculation simulation (Honda et al., Phys. Rev. D 92 (2015) 023004) (Fig. 3) (related to primary cosmic rays, solar activity, geomagnetism, atmosphere, interaction and secondary particles).

We are also searching for hadron showers across the detector area. In addition to being a calibration source throughout the detector, there is also the possibility of atmospheric γ-ray identification by coincidence with charged particles. Currently, we have achieved the detection of hadron shower events that are significant for random chance coincidence, and are studying the calibration of the entire detector and atmospheric gamma ray identification (Fig. 4).

3. Summary and Outlook

We have successfully performed the 2018 balloon-borne experiment. We have achieved the world's highest imaging of the Vela Pulsar, and established the emulsion γ-ray telescope to achieve the world's highest angular resolution. Based on the experience and achievements of the 2018

PoS(ICRC2021)654

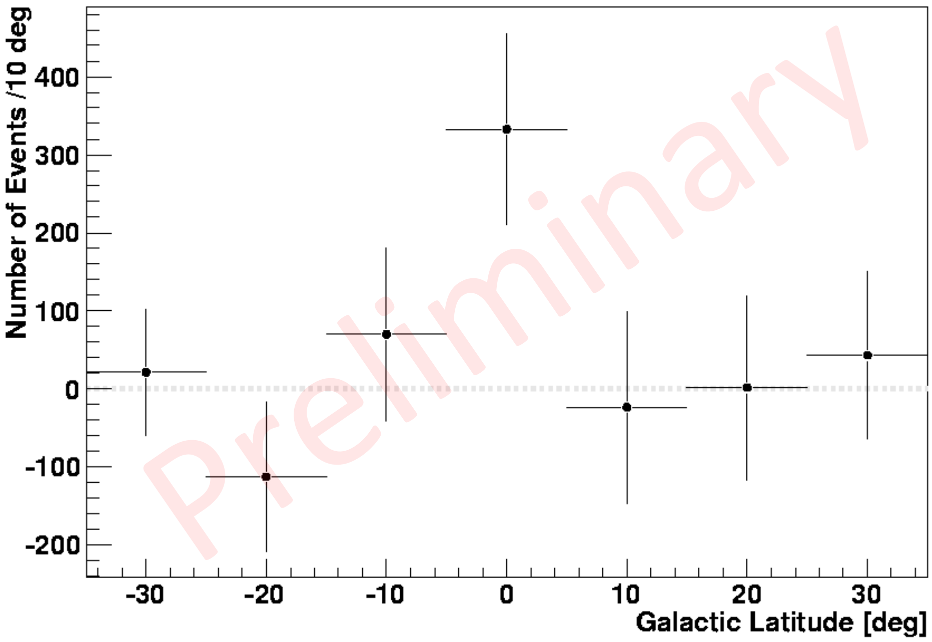

Figure 2: Galactic latitude distribution obtained by subtracting the background distribution model from the observation data (>80 MeV, ~300 <galactic longitude [degree] <~200, excluding Vela pulsar region, detector zenith < 45 degrees). Vertical error bars represent statistical errors.

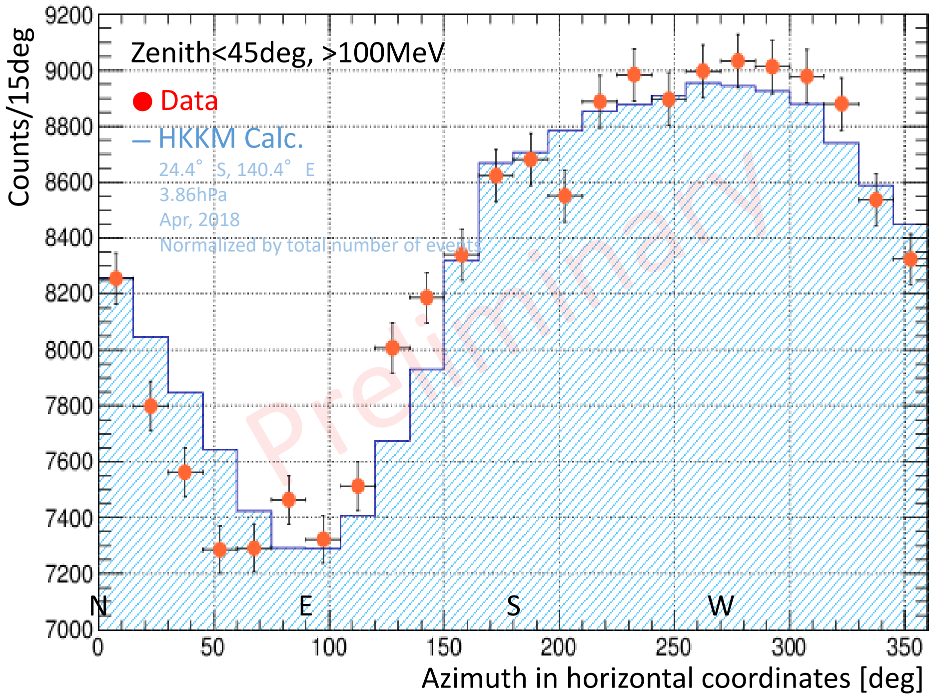

Figure 3: Comparison of atmospheric gamma-ray east-west effect data and HKKM calculation.

PoS(ICRC2021)654

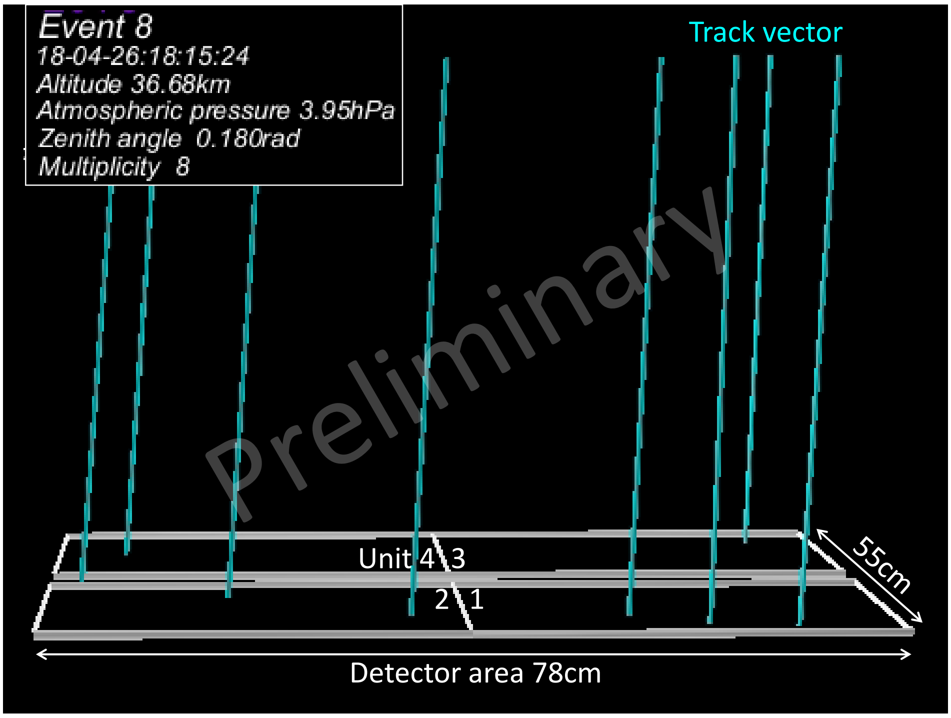

Figure 4: One of detected hadron shower event candidates across the detector area.

balloon-borne experiment, we aim to start scientific observations expanding the aperture area and flight duration repeated balloon flights. In 2023, we plan two balloon-borne experiments in Australia by JAXA Scientific Ballooning with a 2.5 m^2 aperture area and a flight duration in excess of 15 hours. In the 2023 balloon-borne experiments, we aim to achieve the largest aperture area of a γ-ray telescope in this energy regime; observe the Vela pulsar more; observe the Galactic Centre region; observe transient sources; and observe other sources. Currently, we are dedicatedly developing, improving and preparing for the 2023 balloon-borne experiments (Fig. 5).

PoS(ICRC2021)654

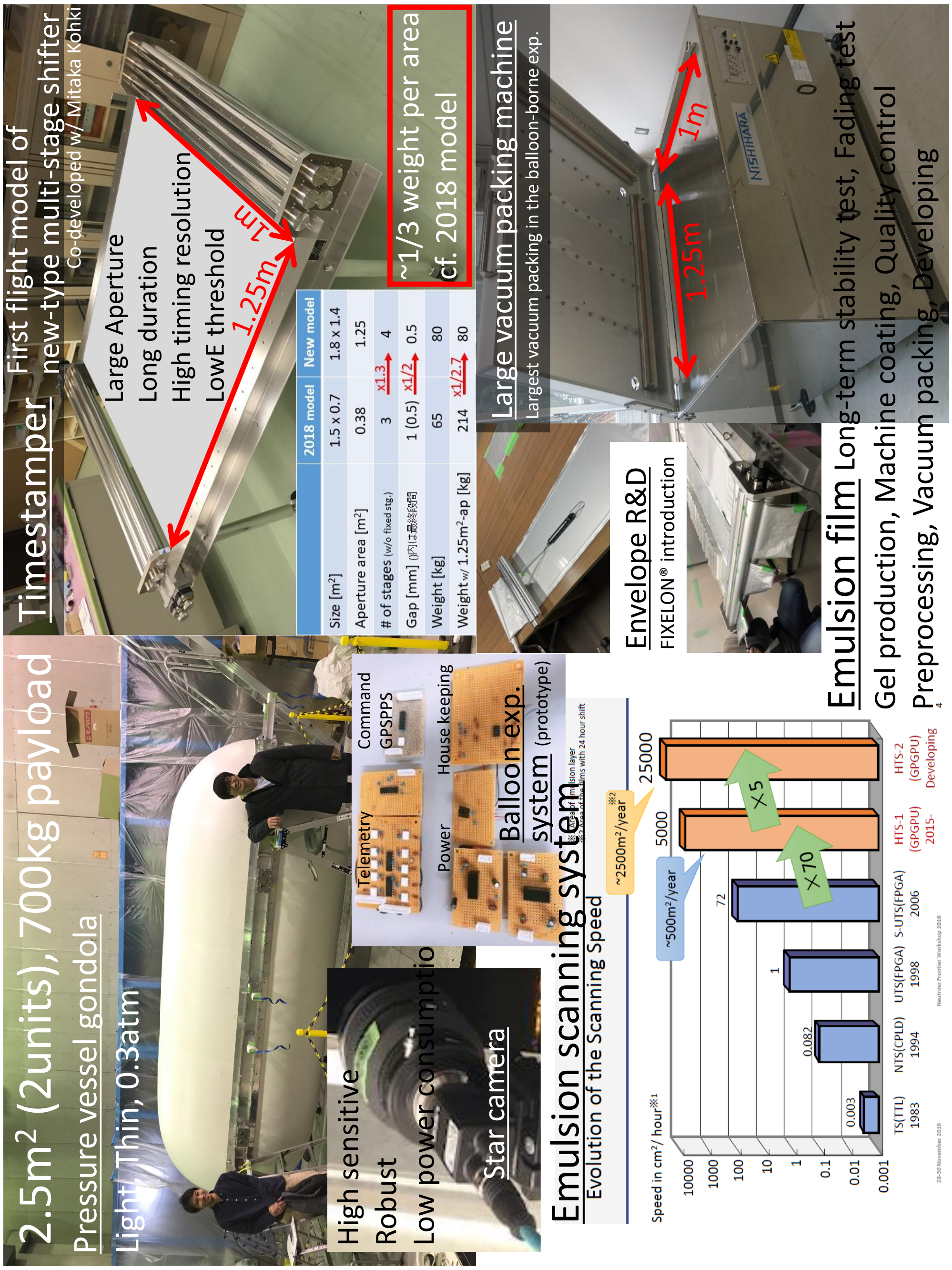

Figure 5: Developments, improvements and preparations for the next balloon-borne experiments.

PoS(ICRC2021)654

References

[1] GRAINE collaboration, Proc. Int. Cosmic Ray Conference (2009, 2013 – 2021).

[2] S. Takahashi et al., Nucl. Instr. Meth. A 620 (2010) 192.

[3] H. Rokujo et al., Nucl. Instr. Meth. A 701 (2013) 127.

[4] S. Takahashi et al., Prog. Theor. Exp. Phys. (2015) 043H01.

[5] K. Ozaki et al., JINST 10 (2015) P12018.

[6] K. Ozaki et al., Nucl. Instr. Meth. A 833 (2016) 165.

[7] S. Takahashi et al., Prog. Theor. Exp. Phys. (2016) 073F01.

[8] K. Yamada et al., Prog. Theor. Exp. Phys. (2017) 063H02.

[9] S. Takahashi, S. Aoki et al., Adv. Sp. Res. 62 (2018) 2945.

[10] H. Rokujo et al., Prog. Theor. Exp. Phys. (2018) 063H01.

[11] H. Rokujo et al., JINST 14 (2019) P09009.

[12] S. Takahashi et al., Prog. Theor. Exp. Phys. (submitted).

[13] Y. Nakamura et al., in preparation.

PoS(ICRC2021)654