PROCEEDINGS OF SCIENCE

Citizen science "Thundercloud Project" – multi-point radiation measurements of gamma-ray glows from accelerated electrons in thunderstorms

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PoS(ICRC2023)1607

It has been a long-standing question whether cosmic rays promote the triggering of lightning and how cosmic-ray air showers interact with the electric field of thunderclouds. The strong electric field in the thunderclouds accelerates electrons to the relativistic regime, of which seed electrons are thought to be supplied from cosmic-ray air shower. Such relativistic electrons emit bremsstrahlung photons in gamma rays, which have been detected by on-ground measurements called gamma-ray glows. Low-altitude winter thunderstorm in Japan provides an ideal environment for observations of gamma-ray glows. We newly launched the citizen science “Thundercloud Project" to construct a multi-point radiation mapping campaign for glows from winter thunderstorms around Kanazawa, Japan. We developed a new handy radiation monitor and shipped about 60 detectors to citizen supporters. The radiation data are stored in the microSD cards in the detectors, and a part of them is remotely sent to the web server so that researchers and supporters can watch the real-time data. In addition, an automatic alert is sent to public Twitter from the server when a glow is detected. The purpose of this project is (1) to characterize the methodological condition of electron acceleration, (2) to investigate whether accelerated relativistic electrons can enhance the chance of the initiation of lightning discharges, and (3) to find a new way of the citizen science to join in the cutting edge science in the physics field. Here we report this growing citizen science project and examples of successful gamma-ray glow observations. Our first scientific result from this citizen science project was published in Tsurumi et al., GRL 2023 [1], where we reported lightning discharges started in or near the electron acceleration site of a gamma-ray glow.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

1. Short history of high-energy atmospheric physics in Japan

High-energy atmospheric physics is a growing research field that studies high-energy phenomena in lightning and thunderclouds [2]. The strong electric field of lightning and thunderclouds accelerates electrons, which strike the atmosphere and cause bremsstrahlung photons to be observed by satellites, aircraft, and ground. One such phenomenon is gamma-ray glow, in which gamma rays of about 10 MeV fall around thunderclouds for several minutes or more [1]. This section reviews a history of on-ground gamma-ray glow observations in Japan.

In 1997, a gamma-ray dose increase was observed from thunderstorms around a nuclear facility at Fukui in Japan [3]. Stimulated by such a finding, in 2006, we developed a new dedicated radiation detector to observe gamma rays from thunderclouds, and the first detection was made in 2007 at a nuclear power plant at Niigata along the Sea of Japan [4]. Subsequent measurements of this GROWTH (Gamma-Ray Observation of Winter THunderclouds) collaboration were further performed continuously at this site, and several gamma-ray glows were successfully detected [5–7]. Figure 1 shows the expected mechanism of gamma-ray glow generation in thunderstorms. When an updraft generates a cumulus cloud, charge separation occurs, creating a strong electric field region. When a cosmic-ray air shower enters this region, electrons are expelled, accelerated, and avalanche-amplified. The electrons further interact with the atmosphere producing bremsstrahlung photons in the MeV range falling to the ground.

In the following year, 2007, the gamma-ray glow was also detected at an observatory installed at 2770 m altitude on Mt Norikura [8]. Abrupt termination of a gamma-ray glow associated with lightning discharges has also been observed, which is interpreted to be the disappearance of the electric field in thunderclouds due to the discharge[6, 9, 10]. Recently, there has been also research on meteorological conditions for gamma-ray glows [11, 12], theoretical modeling [13–15], and a new imaging radiation detector [16]. During our observations of gamma-ray glows, we also discovered that terrestrial gamma-ray flashes (TGFs) produced by lightning discharges can cause photoneutron reactions in the atmosphere [10, 17–20], emitting neutrons and positrons into the atmosphere. Since this discovery, not only gamma-ray glow but also ground-based TGF observations and associated photoneutron reactions have been intensively studied [18, 21, 22].

As gamma rays fly only a few hundred meters in the atmosphere, it is essential to establish a multi-point observation network to increase the number of detections and to reveal the shape of the gamma-ray irradiated area and its temporal changes. Thus, we have developed a new observation network in Kanazawa to map gamma-ray glows at multiple locations [23–25]. Here we report the recent update of this program utilizing the framework of Citizen Science.

2. Citizen science “Thundercloud project"

Low-altitude winter thunderstorm in Japan provides a rare and ideal environment for detecting gamma-ray glows on the ground experiment. We newly launched the citizen science “Thundercloud Project" to construct a multi-point radiation mapping campaign for glows from winter thunderstorms around Kanazawa, Japan, to increase observations’ density and area coverage.

[1]This phenomenon is also referred to long bursts or thunderstorm ground enhancements

For this program, we developed a new portable (3 kg), one-button-operated radiation detector named Cogamo (Compact Gamma-ray Monitor) and shipped them to citizen supporters (Figure 2). The Cogamo uses a CsI(Tl) scintillator (5 cm×5 cm×15 cm) coupled with a Silicon Photomultipliers (SiPMs) MPPC (Multi-Pixel Photon Counter) and covers gamma-ray spectroscopy in the ~0.2–10 MeV energy range. The individual radiation events are detected with the GPS time-tagging and stored in the microSD cards. Environmental information (e.g., ambient temperature, humidity, optical luminosity, and atmospheric pressure) is also recorded as housekeeping (HK) data. Some data are remotely sent to the web server so researchers and citizen supporters can watch the real-time monitoring data. When a gamma-ray glow is detected with the count rate exceeding the predetermined threshold, an automatic alert in the server is sent to the public on Twitter [1].

The objectives of this Citizen Science project cover both scientific results and education and outreach. Scientifically, the goal is to provide a complete picture of gamma-ray glow and its relationship to lightning discharges. The mechanism of gamma-ray glow is assumed to be as shown in Figure 1. However, it is still at the hypothetical stage. Thus, we would like to accumulate observational evidence to reveal a comprehensive picture. For example, the following questions need to be answered: "When does electron acceleration in thunderclouds start, how long does it continue, and how does it end?", "What kind of thunderclouds form a strong electric field where electron acceleration can occur?", “How do these high-energy atmospheric phenomena within the clouds relate to the triggering of lightning? Could electrons accelerated by the electric field in thunderclouds develop into the onset of lightning, or could they be initiated by air showers of high-energy cosmic rays interacting with a strong electric field?"

The Cogamo detectors were distributed to citizen supporters around Kanazawa, as shown in Figure 3. We have already detected many gamma-ray glows, some of which were observed in multiple codgers simultaneously, so we were also able to measure the spatial extent of the gamma-ray glow. Figure 4 shows an example of the detected gamma-ray glow events by our Cogamo detectors compared with radar measurement of a moving thundercloud. Figure 5 shows the gamma-ray spectra of this glow compared with the environmental radiation background. Since the gamma-ray glows are sufficiently bright above 3 MeV than the astrophysical gamma-ray bursts measured in space, such a small observation system is sufficient to make statistically significant detections.

2.1 Aspects of the outreach and education

This Citizen Science activity is considered highly effective for outreach and education because familiar natural phenomena are at the cutting edge of scientific research. The project team has held an annual in-person workshop each year. Figure 6 is a photo from a workshop at Kanazawa in FY2022. Graphic recording was employed to illustrate discussions in real-time. In addition to lectures by researchers, the team discussed with citizen supporters how to create a culture using lightning. In addition, in FY2023, the project gave a scientific lecture to high school students in Nanao City at a high school. The Thundercloud Project is also promoting the practice of self-building, calibration, and deployment of radiation measuring instruments as physics education, not only for graduate students but also for undergraduate students (e.g., [26]). Such a citizen science activity has gained wide attention in the community [27].

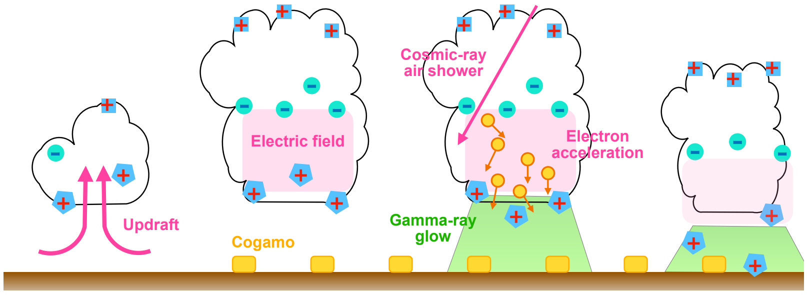

Figure 1: Schematic view of the assumed mechanism of gamma-ray glows in a life cycle of thunderstorms.

Figure 2: (left) Photo of a compact gamma-ray monitor (CoGaMo) used by the citizen science "Thundercloud Project." (right) Multiple Cogamos with turning on the LED lights on the detector boxes.

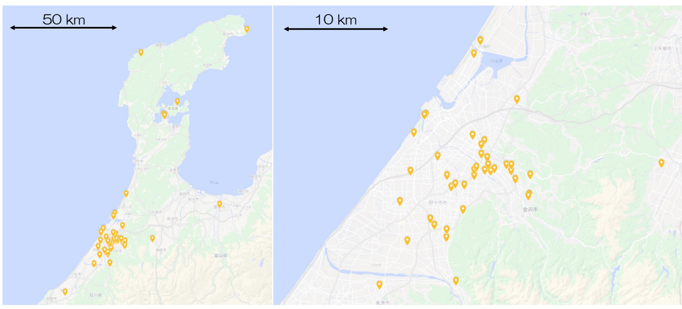

Figure 3: Location of Cogamo (yellow marker) of Thundercloud Project in Kanazawa in the winter of the fiscal year 2021 [26]. (Left) Map around Ishikawa Prefecture (Right) At the center of Kanazawa City, where the observation network was developed with particular emphasis. Created from Google Maps.

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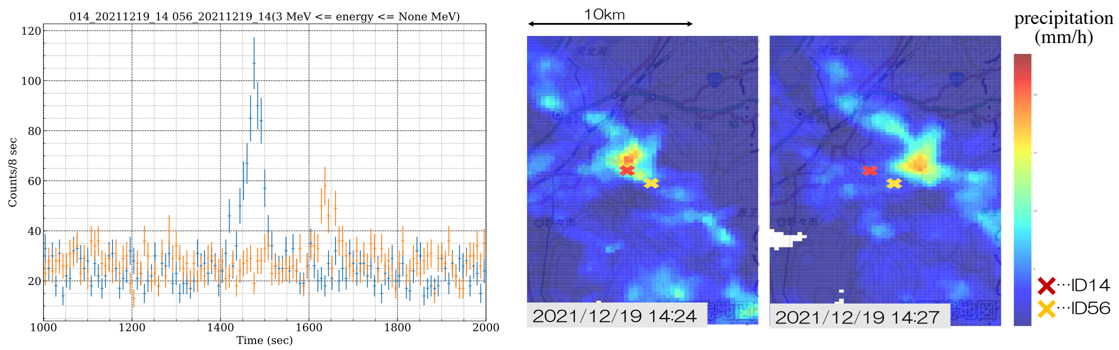

Figure 4: (Left) Example of a gamma-ray glow event detected by the Citizen Science Thunderclouds Project in Kanazawa, Japan, at 14:20 (JST) on 19 December 2021. Time variation of radiation count rates above 3 MeV for Cogamos ID 14 (orange) and ID 56 (blue), shown in 8-sec binning [26]. XRAIN weather radar image for this event. The crosses indicate the location of Cogamo ID 14 (red) and ID 56 (yellow), corresponding to 14:24 and 14:27, respectively (modified from [26]).

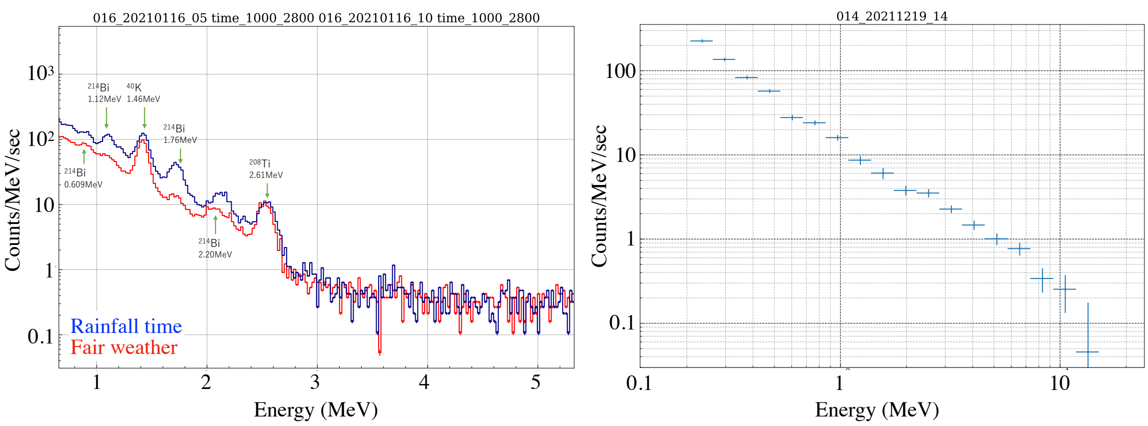

Figure 5: (Left) The energy spectrum of the environmental radiation background recorded by Cogamo ID 16 on 16 January 2021. Blue and red data indicate precipitation at around 10:20 JST and fair weather at around 5:20, respectively (modified from [26]). (Right) The energy spectrum of a gamma-ray glow detected on 19 December 2021 by Common ID 14. Background spectrum was subtracted [26].

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Figure 6: Citizen Science Workshop “creating culture from lightning", an exchange event between citizen supporters and the Thundercloud Project, held in Kanazawa on 9 July 2022. On the left is a photo of the lecture, and on the right is an illustration of the discussion recorded by graphic recording.

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