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Observation of gamma-ray bursts from winter thunderclouds and lightning over the Japan sea coast

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Gamma-ray emission associated with lightning and thunderstorms are reported nowadays. This phenomena was first detected in space by gamma-ray observing sattelite and recently numbers of ground based observation experiments are also carried out. GROWTH (Gamma-Ray Observation of Winter THunderclouds) experiment has been operated since 2006 in Kashiwazaki-Kariwa nuclear power plant located in Niigata prefecture and observing gamma-ray emission from winter thunderclouds over the Japan sea coast region. This experiment reveals that there are two types of bursts. One is called "short-burst" which coincides with lightning discharge and has duration of less than 1 sec. The other type is called "long-burst" which continues more than a minute correlated with thunderclouds and not the discharge(H. Tsuchiya+2007, 2011). Long-bursts normally have a featureless spectra which can be explained by Bremsstrahlung emission from relativistic electrons accelerated by the electric field in the thunderclouds. Typical duration of long-bursts are about 1 min. This time scale is equal to the passage time of a typical thundercloud spreading over ˜1 km size with speed of ˜15 m/s, but may also be an intrinsic lifetime of emission. Essential factors such as, what makes it start, its intrinsic duration and what causes it to terminate, still remain unknown.

At 09:27 (JST) on January 13th in 2012, GROWTH detected curious emission. A short-burst was triggered, correlated with in-cloud discharge within 200 ms, and a long-burst started at the same time with the duration of more than 1 min, with fast rising and exponentially decaying intensity with time constant of 30 sec.

One of the remarkable point of this burst is strong 511 keV electron-positron annihilation line in the spectrum. Equivalent width, the parameter which shows a relative strength of a line compared to a continuum component, of the 511 keV line is usually ˜50 keV. It is 280 keV for the present event, which is 5 times more prominent than usual. As a simplest explanation, this relatively strong line can be explained as follows: Bremsstrahlung gamma-rays are selectively emitted toward the direction of the accelerated seed electrons. The gamma-ray energy as well as its number rapidly decreases with opening angle to the electron direction, forming a gamma-ray beam. If electrons are accelerated in parallel in a 'bulk' electric field, this effect becomes easily observable. High-energy gamma-rays with energy $>$1 MeV can create positrons and eventually isotropic 511 keV emission. If the detector is slightly off the beam, it will observe smaller numbers of those high energy photons, while it wil detect relatively conspicious 511 keV photons. Such 'beam' effect is actually reported as a change in the gradient of the continuum spectrum distribution vs. time as a thundercloud goes by, already(H. Tsuchiya+2009, 2013).

Another remarkable point of this long-burst is the abrupt initiation correlated with the discharge. Abrupt termination of a long-burst correlated with lightning discharge is already reported(H.Tsuchiya+2013), which can be consistently explained by an electric field dissapearance caused by a discharge. In the present burst, although still controversial, it is possible that the discharge causes the rapid reorganization of electric field within the thundercloud, resulting in start of the electron acceleration.

To testify explanation above and to measure intrinsic intensity vs. time, another new detector with higher sensitivity with a limited angular resolution was developed and set up in the nuclear power plant in Nov. 2014. As a result, this detector succeeded in observing 6 events within a single winter period. This burst occurance rate is about 4 times greater than usual: 12 long-bursts during 2006 and 2013. One of these events with the highest statistics shows a sign of gamma-ray beam. Another event has abrupt termination feature again, which is the second detection of such event by GROWTH.

Keywords: gamma-ray observation from thunderclouds, TGF, positron generation