

# Multi-point radiation measurements for gamma-rays from accelerated electrons in winter thunderstorm

雷雲ガンマ線の多地点観測プロジェクトが拓く新展開

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see also talk by Wada @MIS18-05, 5/22 (today) 11:45 AM-12:00 PM

JpGU-AGU Joint session M-IS05 (Thunderstorm and Lightning) @ Chiba, Japan, 2017/05/22 (15 min)

<http://pcwallart.com/image-post/183236-thunderstorm-wallpaper-1.jpg.html>

# Electron Acceleration in Electric Fields

- Electron acceleration is usually difficult under dense atmosphere (short range of electrons).
- High energy radiation measurements from
  - thunderstorms (MacCarthy et al., 1985; Eack et al., 1996)
  - natural lightnings (Moore et al., 2001)
  - rocket-triggered lightnings (Dwyer et al, 2003)
  - Terrestrial Gamma-ray Flashes (TGFs) in a low-Earth orbit from satellites (Fishman et al, 1998; Smith et al., 2004)
- Relativistic acceleration of electrons by electric fields both in thunderstorms and lightnings?
- Prolonged high energy radiation enhancements detected for a few minutes from Japanese winter thunderstorms (Yamasaki et al., 1998; Torii et al., 2002)



Dwyer et al., 2003, Science

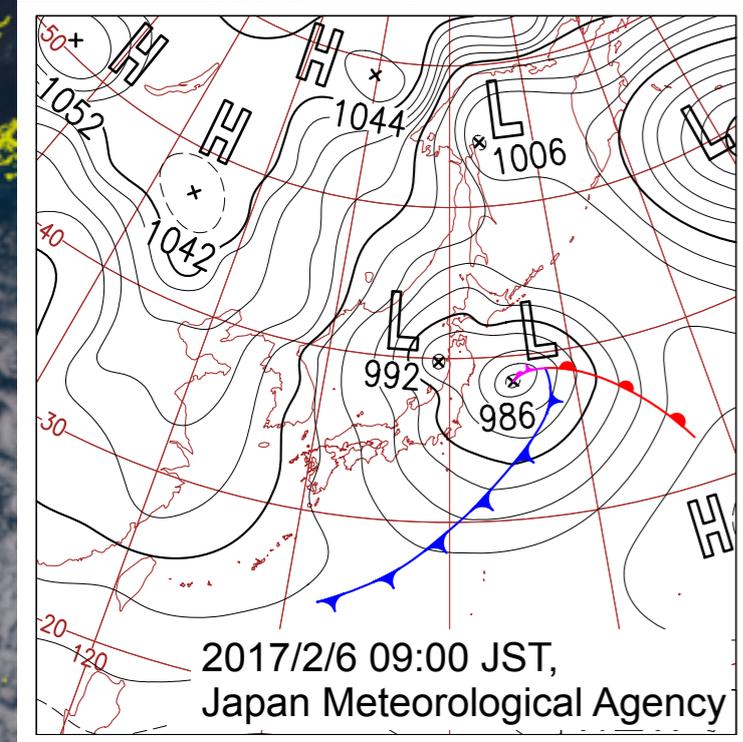
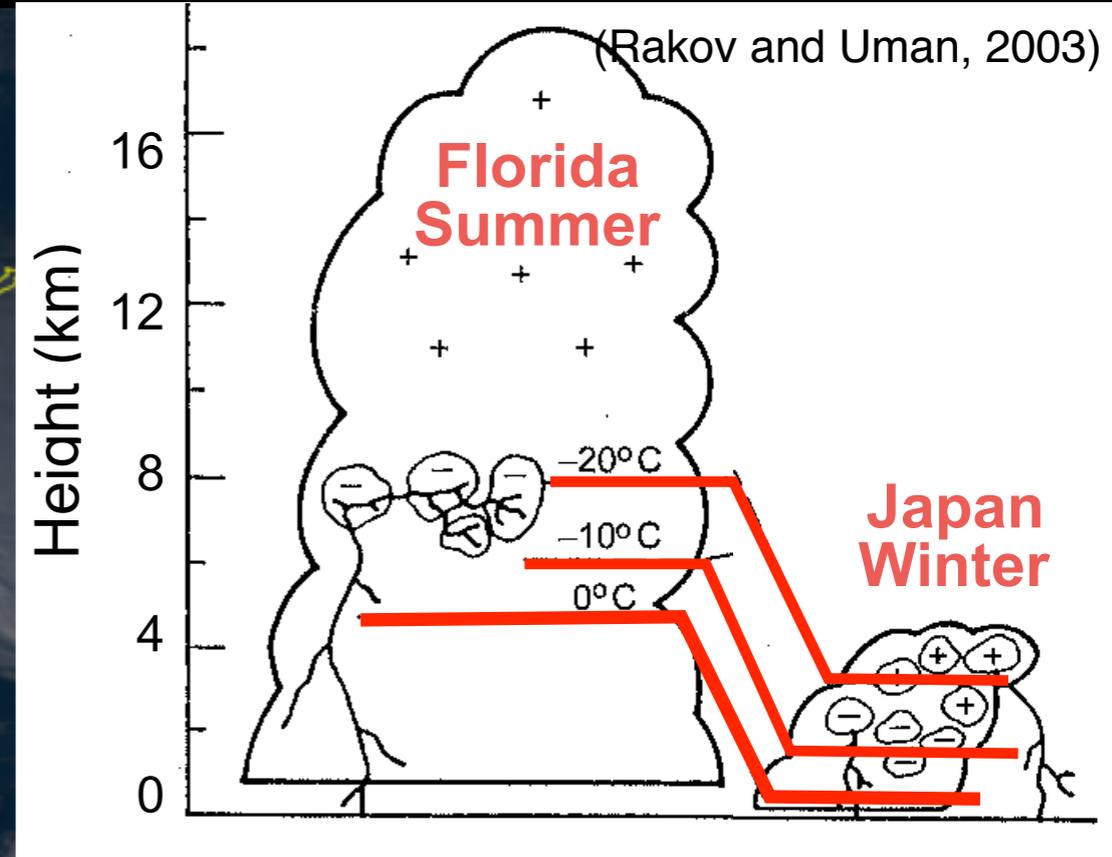
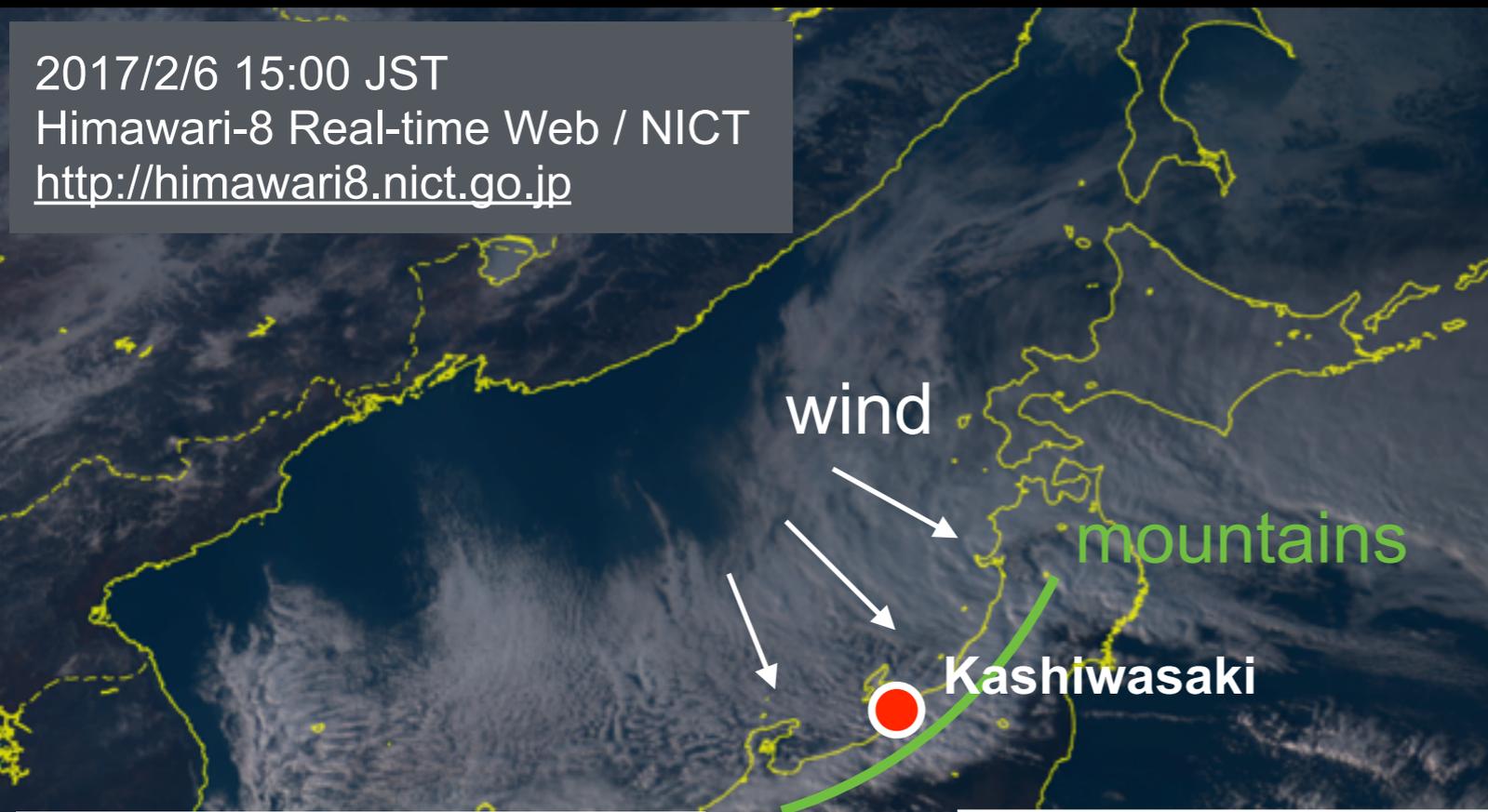
**Question: Radiation mechanism, event rate, and atmospheric condition?**

- Gamma-Ray Observation of Winter Thundercloud (GROWTH) project since 2006 (Tsuchiya, Enoto et al., 2007 PRL, 2009 PRL, 2011 JGRD, and 2013 PRL).

# Winter Thunderstorms along the Japan Sea

Periodic wind from the northeast, originating from the Siberian cold front, provide a rare environment for thunderstorm with high energy phenomena.

2017/2/6 15:00 JST  
Himawari-8 Real-time Web / NICT  
<http://himawari8.nict.go.jp>



## Unique properties of Japanese winter thunderstorm:

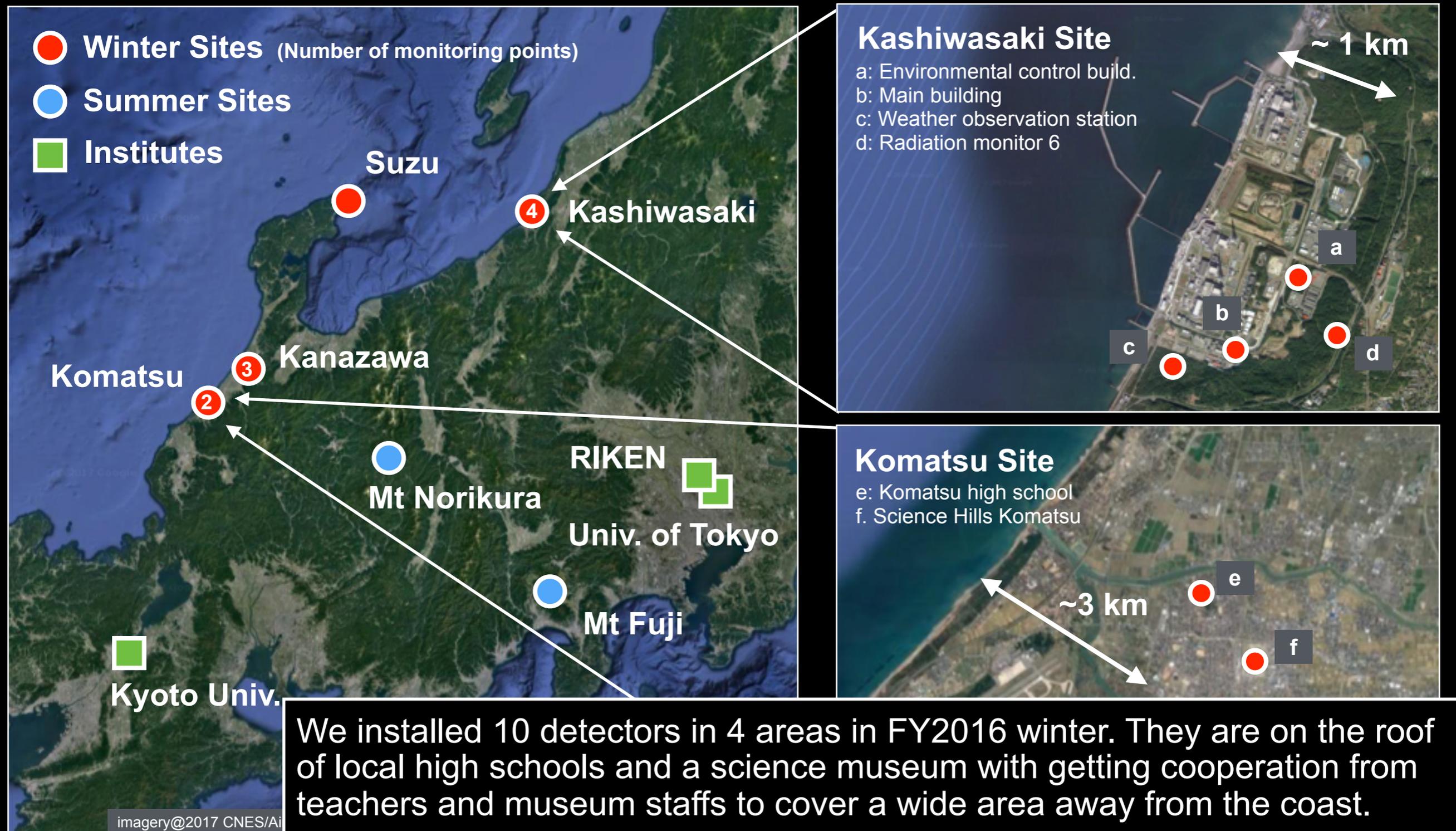
- low altitude (sometimes <1 km),
- powerful ( $\times 10^{1-3}$ ) and frequent lightnings,
- higher rate of positive discharges (~33%),
- and sprite & elves above the sea.

Under strong thunderstorms, we have been detected >20 gamma-ray events for 10 years at Kashiwasaki.

- 10 MeV gamma-ray range is several hundred meter on ground (a several dozen m of 10 MeV electron).

# Observation Sites of the GROWTH Project

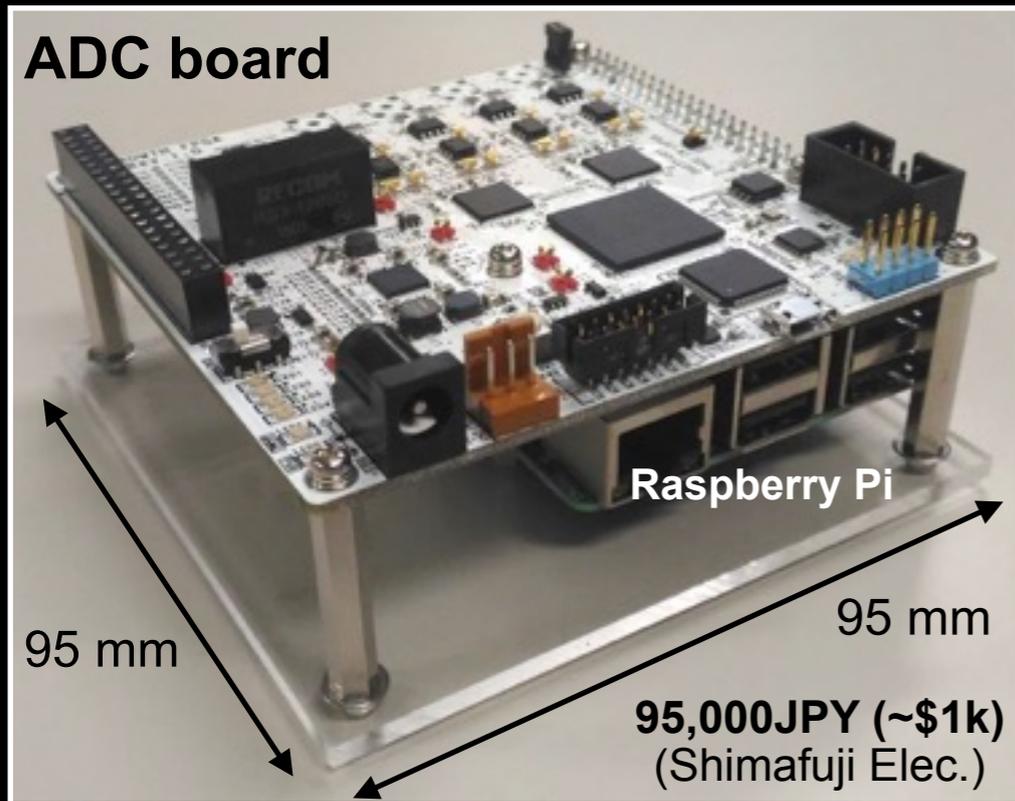
We started a new multi-point mapping observation since 2015 to increase the sample of the high energy events and to trace moving thunderstorms.



Our winter observations have been supported by Kashiwasaki-Kariwa power station & TEPCO, Inc., Kanazawa University, Kanazawa University Senior High School, Izumigaoka High School, Ishikawa Komatsu High School, and Science Hills Komatsu

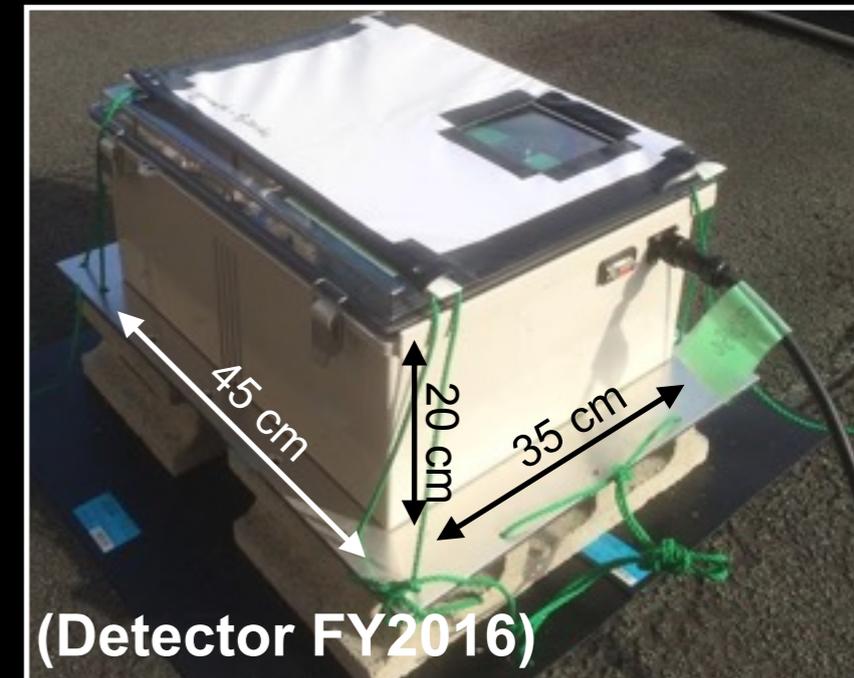
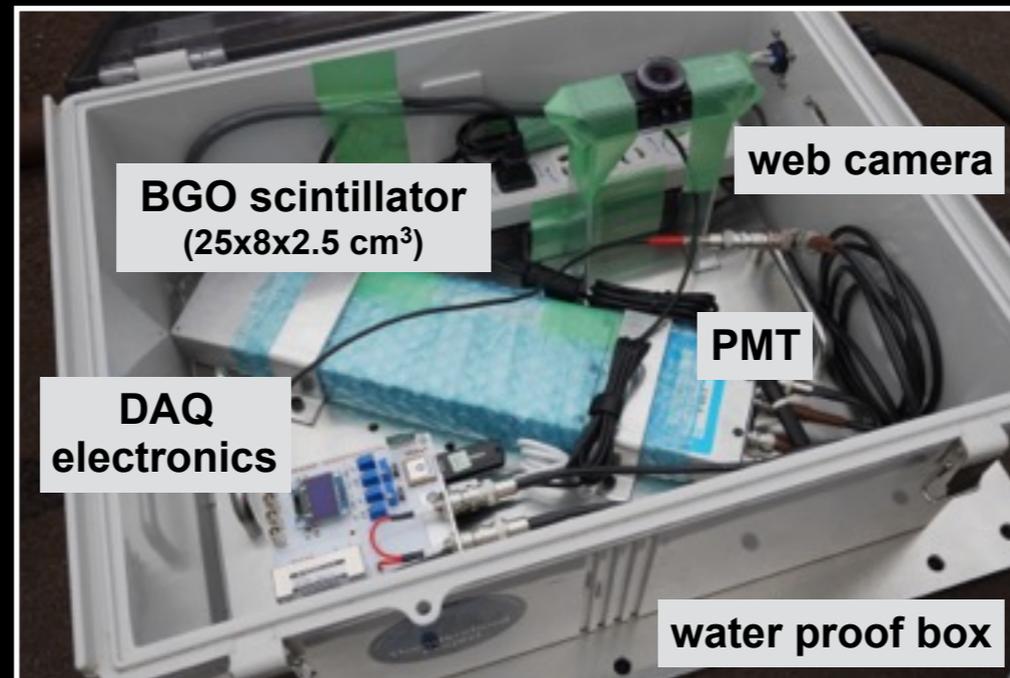
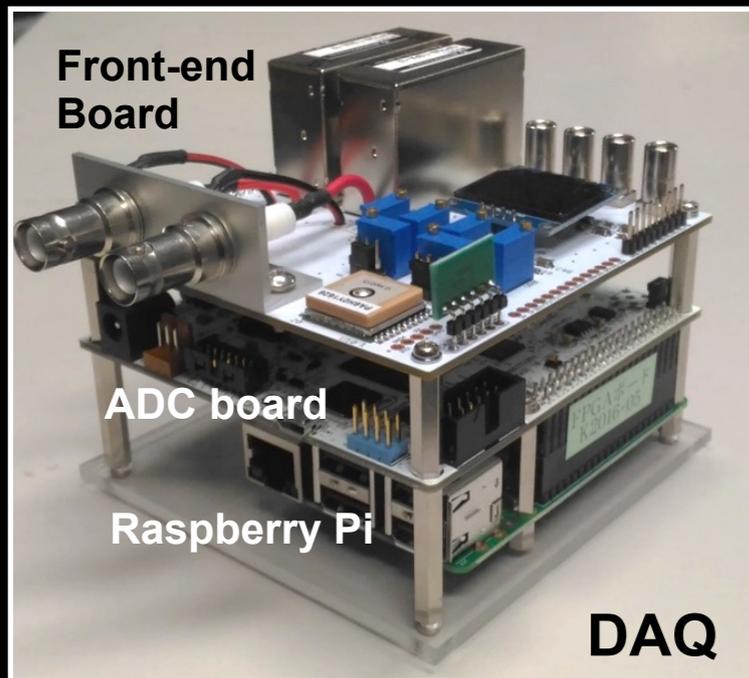
# Low-cost DAQ System Controlled by RaspPi

We newly develop a “stand-alone” & “low cost” data acquisition system (DAQ) with two electronics boards (Front-end & ADC) controlled by Raspberry Pi3.

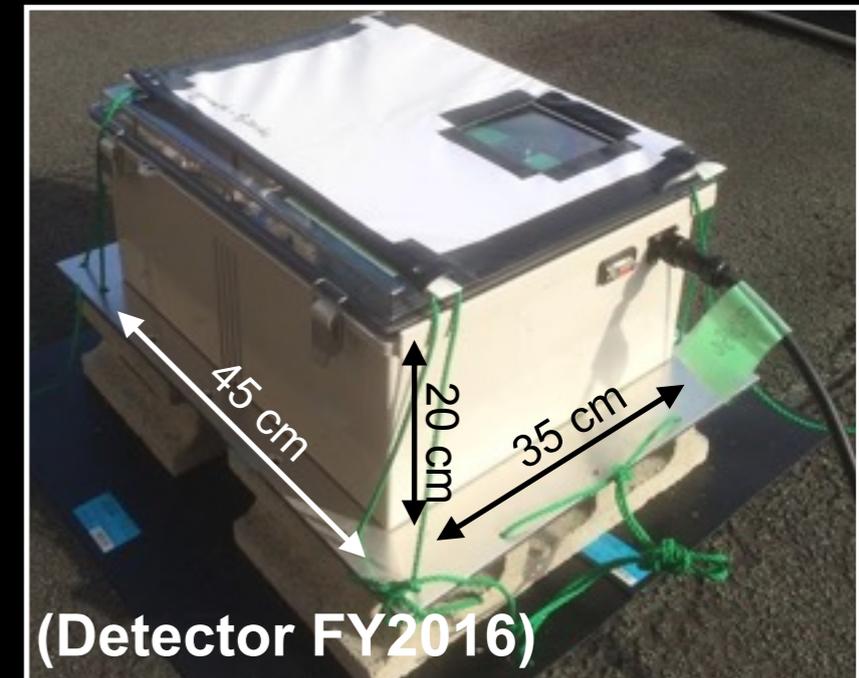
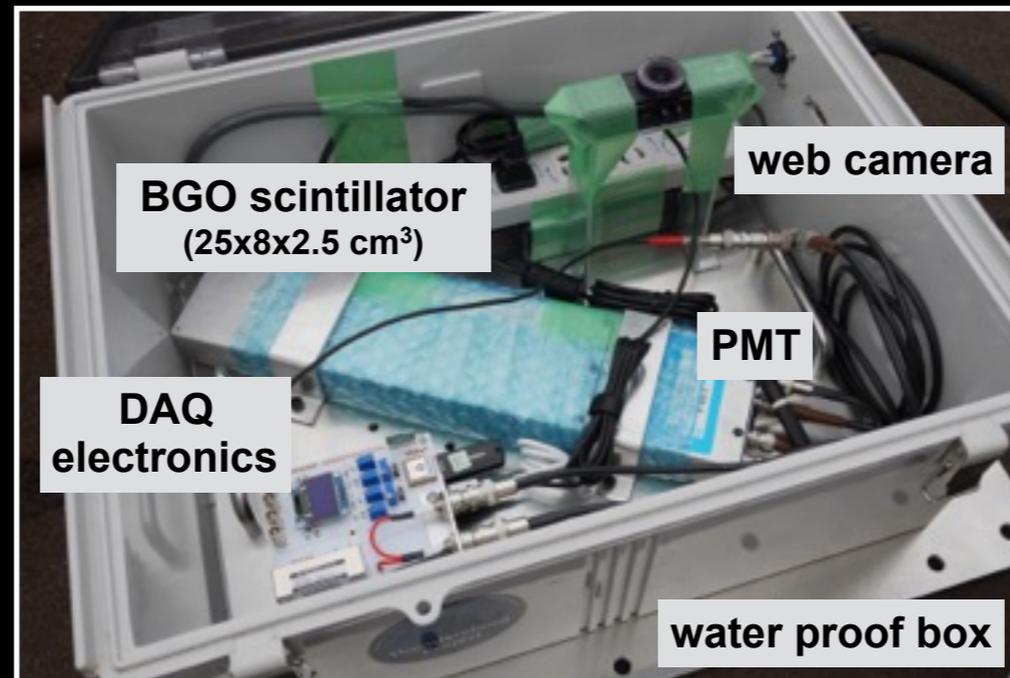
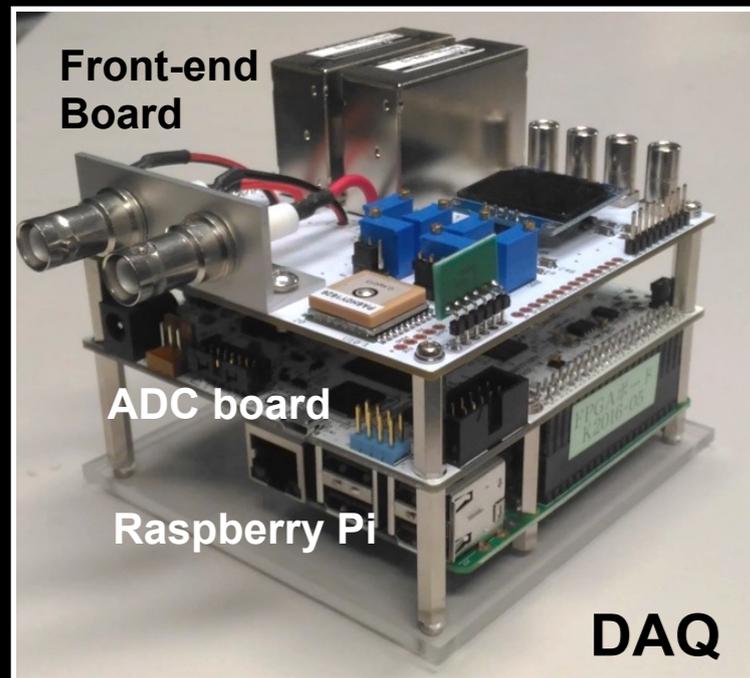
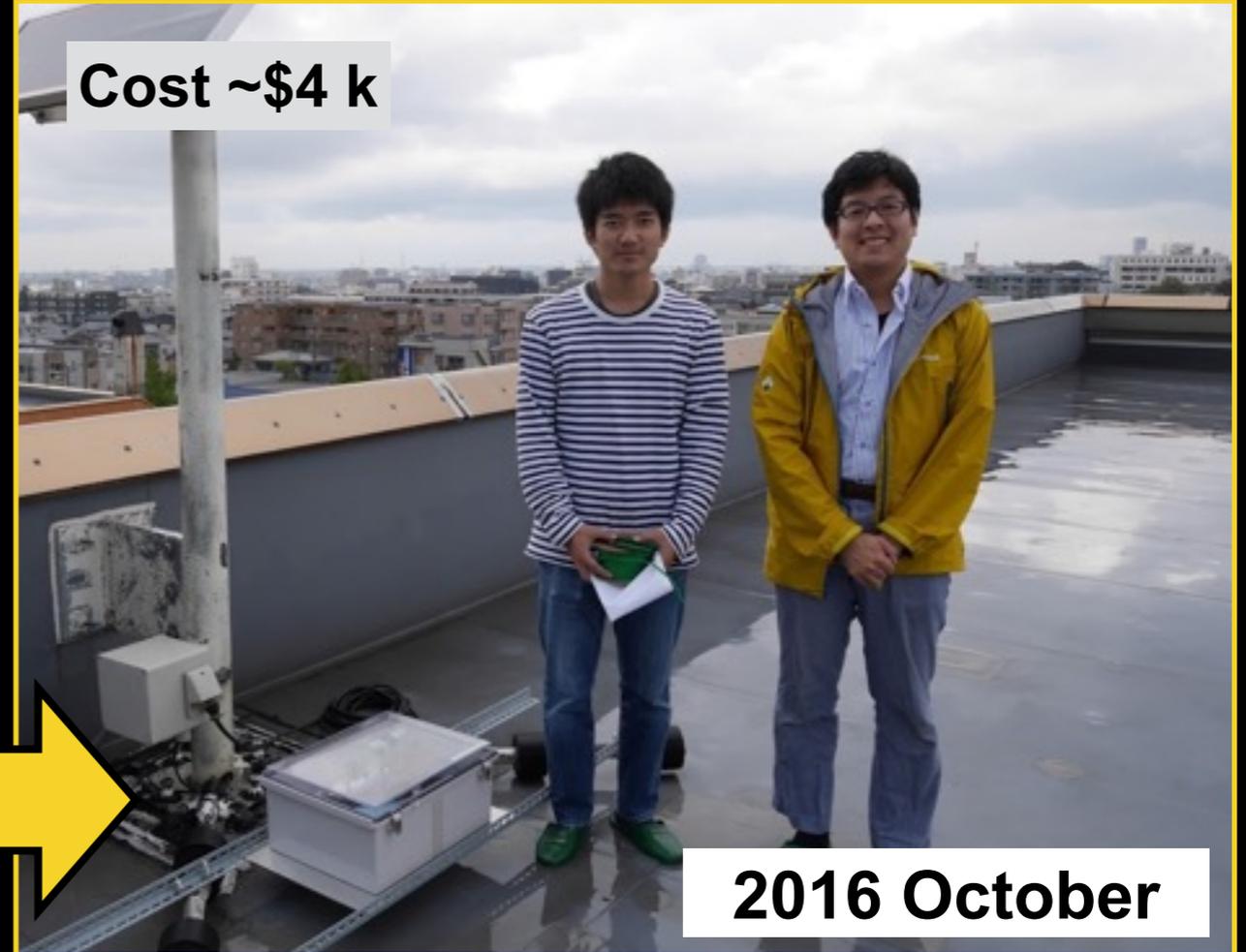


- Gamma-rays detected with BGO scintillators
- Each photons recorded with energy and time
- GPS time tag, and on-board display of DAQ
- Environmental sensors (temperature, pressure, etc)
- Mobile data transfer & remote control
- Real-time monitoring of the website

(ref) FPGA/ADC board specification (50 MHz x 12 bit, 4 ch ADC)  
<http://ytkyk.info/blog/2016/09/04/growth-fpga-adc-board/> (C) T. Yuasa



# Low-cost DAQ System Controlled by RaspPi



Wada, Master thesis of the University of Tokyo, "Construction of the multi-point observation network for thundercloud gamma-rays"  
See the talk by Wada @ MIS18-05 at this JpGU, 5/22 (today) 11:45 AM - 12:00 PM for details

# Academic Crowdfunding

学術系クラウドファンディングサイト academist (アカデミスト)



日本海沿岸に  
した。とても

年の雷を思い出しま  
応援しています。

## Original Return (Reward)

designed by Adachi design Lab.



Mug

Original T-shirt



Acknowledgement & USB

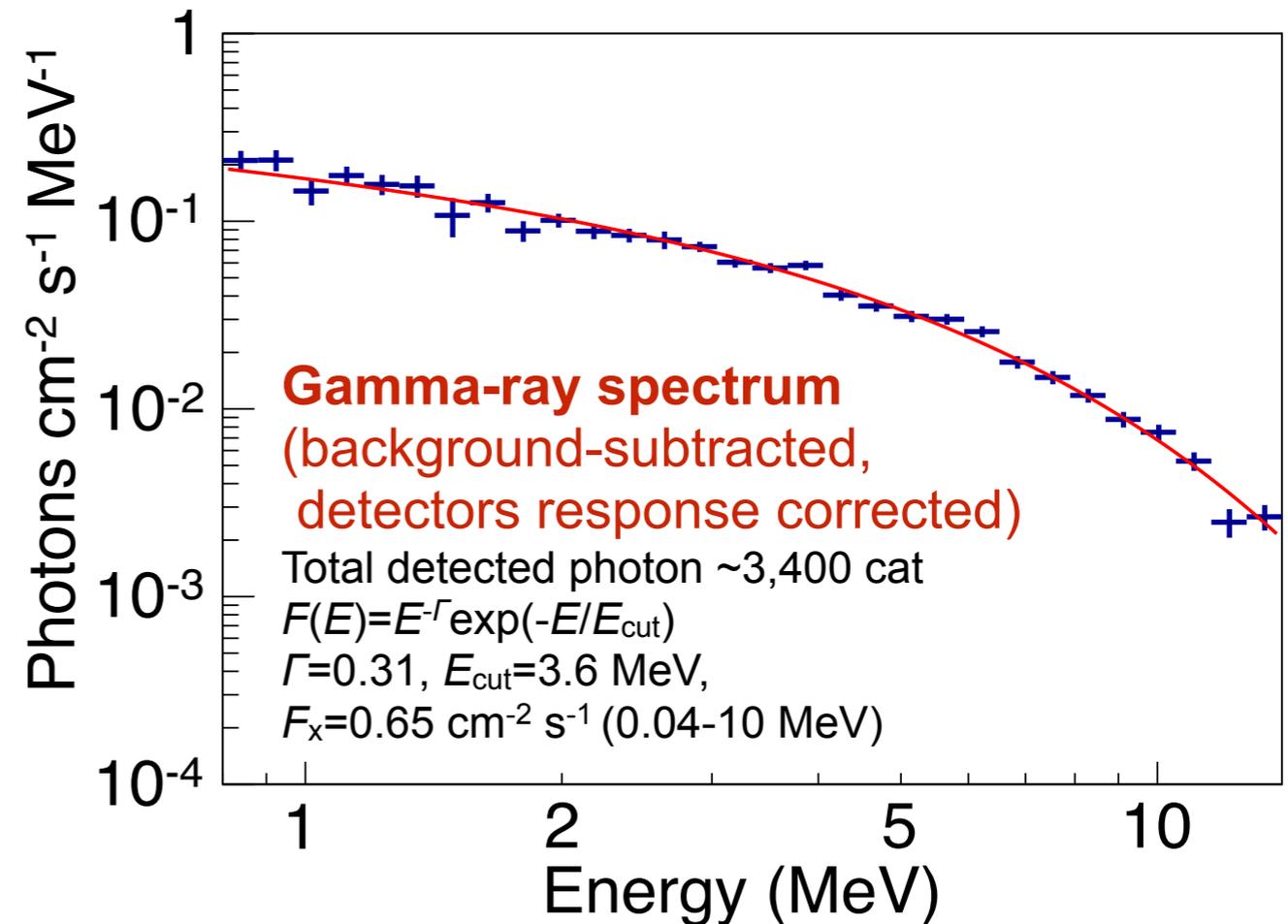
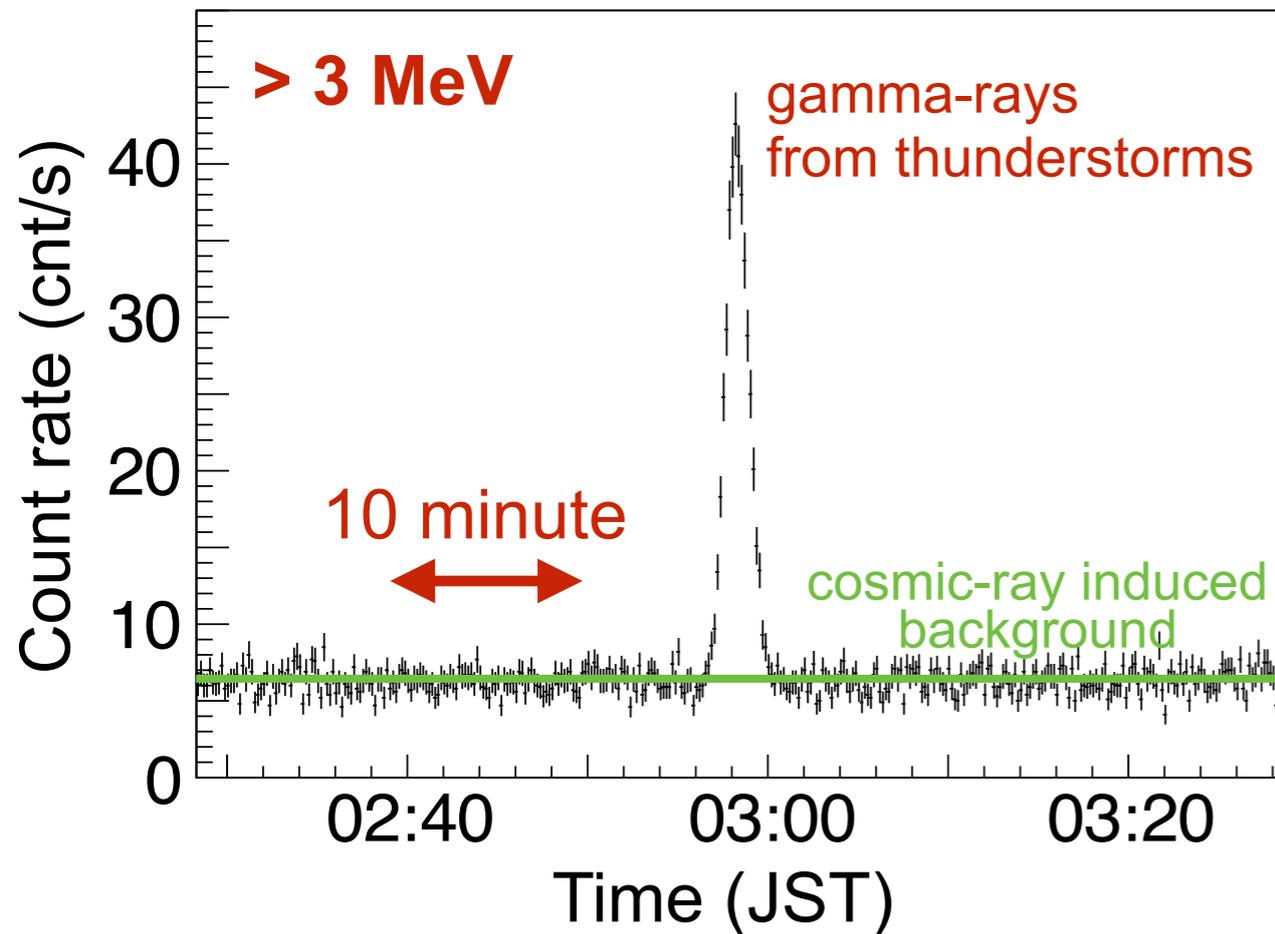
At the initial phase of our project, citizen supporters financially helped us through the academic crowdfunding. The donation gathered during the two month was ~\$16k from 153 contributors. This has been used for prototype manufactures and preparing for power-plugs on the high school roofs.

**Thank you for your support : )**

Since 2015, our project has been supported by the crowd funding "academist", Grants-in-Aid for Young Scientists (A) Kakenhi 16H06006, the SPIRITS program of Kyoto University, and the joint research program of the ICRR, University of Tokyo.

# Gamma-rays Detected from Thunderstorms

Example: Prolonged (~2 min) gamma-rays detected on 2016 December 8, ~3:00 (JST) at Science Hills Komatsu as a dense cloud passing the above.



**Gamma-rays from winter thunderstorms extend up to at least  $\sim 10$  MeV.**

- Prolonged duration ( $\sim 2$  minute) is consistent with the speed of a moving cloud.
- Also detected at another point with a time lag  $\rightarrow$  Quasi-static electron acceleration
- Cutoff power-law spectrum  $\rightarrow$  Consistent with the electron Bremsstrahlung emission

# Thunderstorms as a Natural Accelerator

Radiations before lightnings?

Cosmic rays

+ charge

- charge

Electron acceleration

Multiplication

+ charge  
(Pocket plus charges)

Bremss.  
Gamma-rays

Lightning  
Discharges

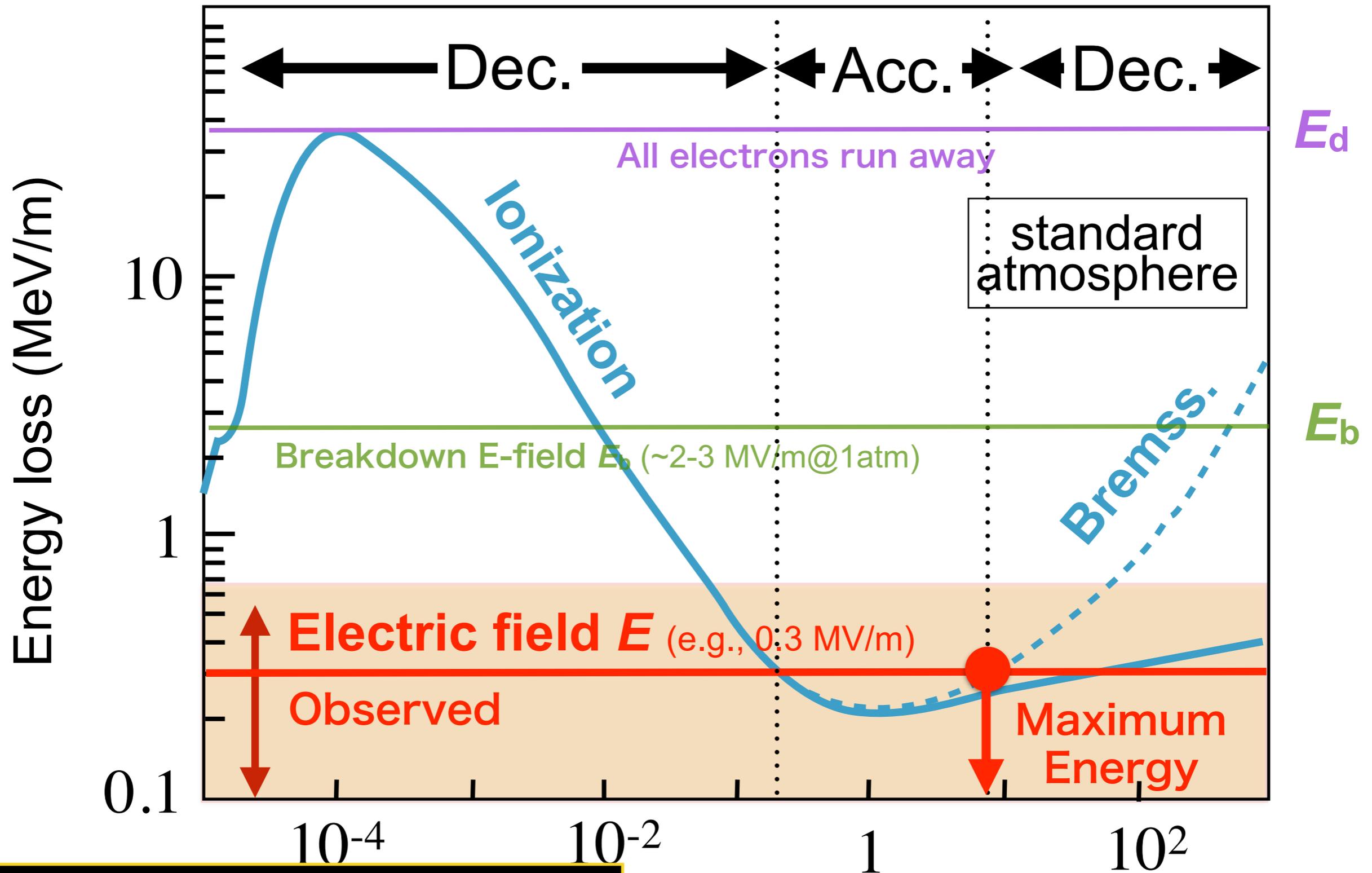
1. Cosmic rays knock out high energy seed electrons (e.g.,  $>100$  keV).
2. Strong electric fields generate the relativistic runaway electron avalanche (RREA).
3. Runaway electrons emit bremsstrahlung gamma-rays when interacted with the atmosphere.
4. Accelerated electrons generate an ionised path of discharge (stepped leader)?
5. As the leader reaches the ground, a huge current runs the path (return stroke).

Tsuchiya, Enoto, et al., PRL 2007, 2009

榎戸, 修論 「雷雲電場による粒子加速の観測的研究」 東大 (2007)

榎戸&土屋 「雷雲は天然の粒子加速器か？」 天文月報 (2008)

# Relativistic Runaway Electron Avalanche



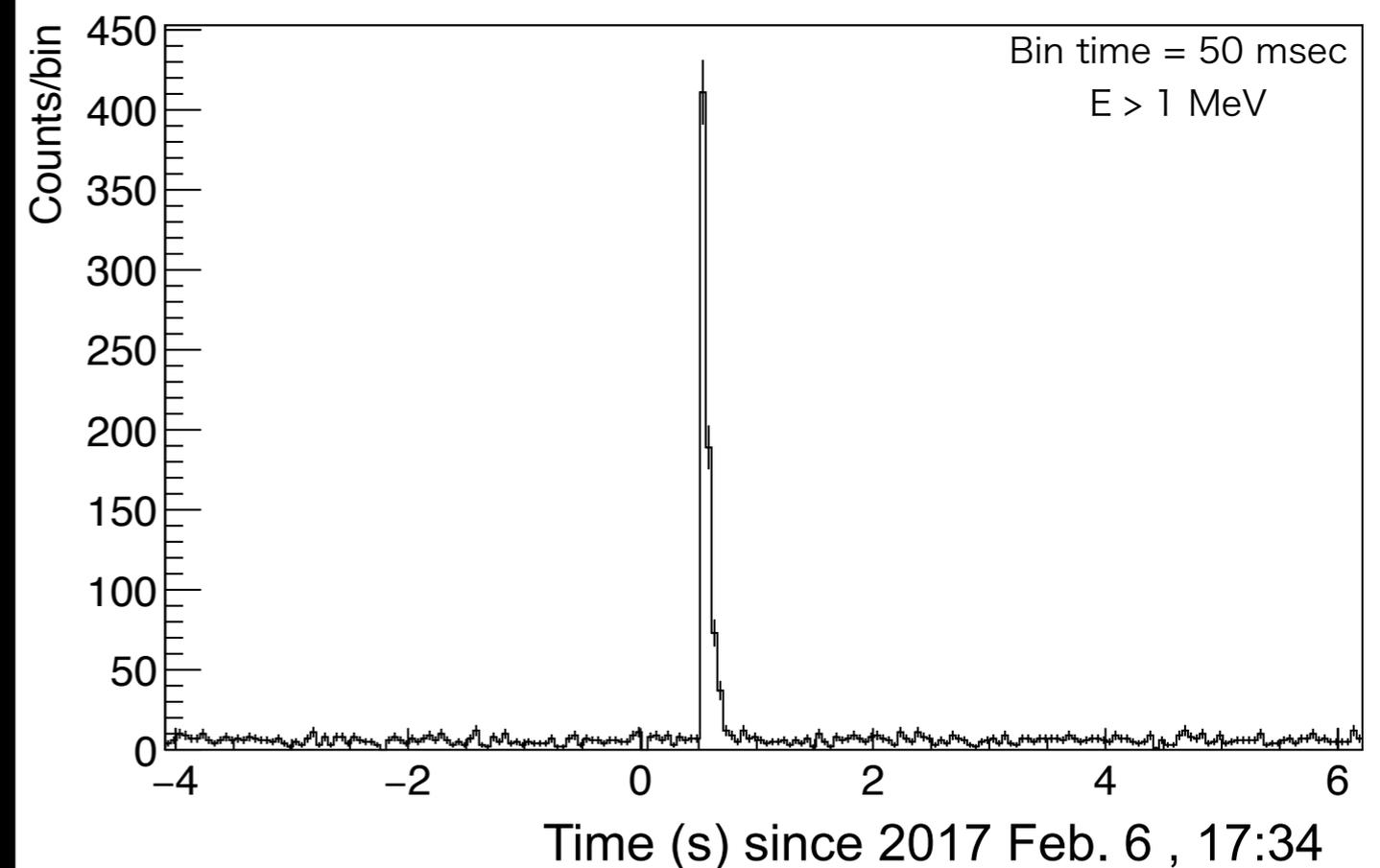
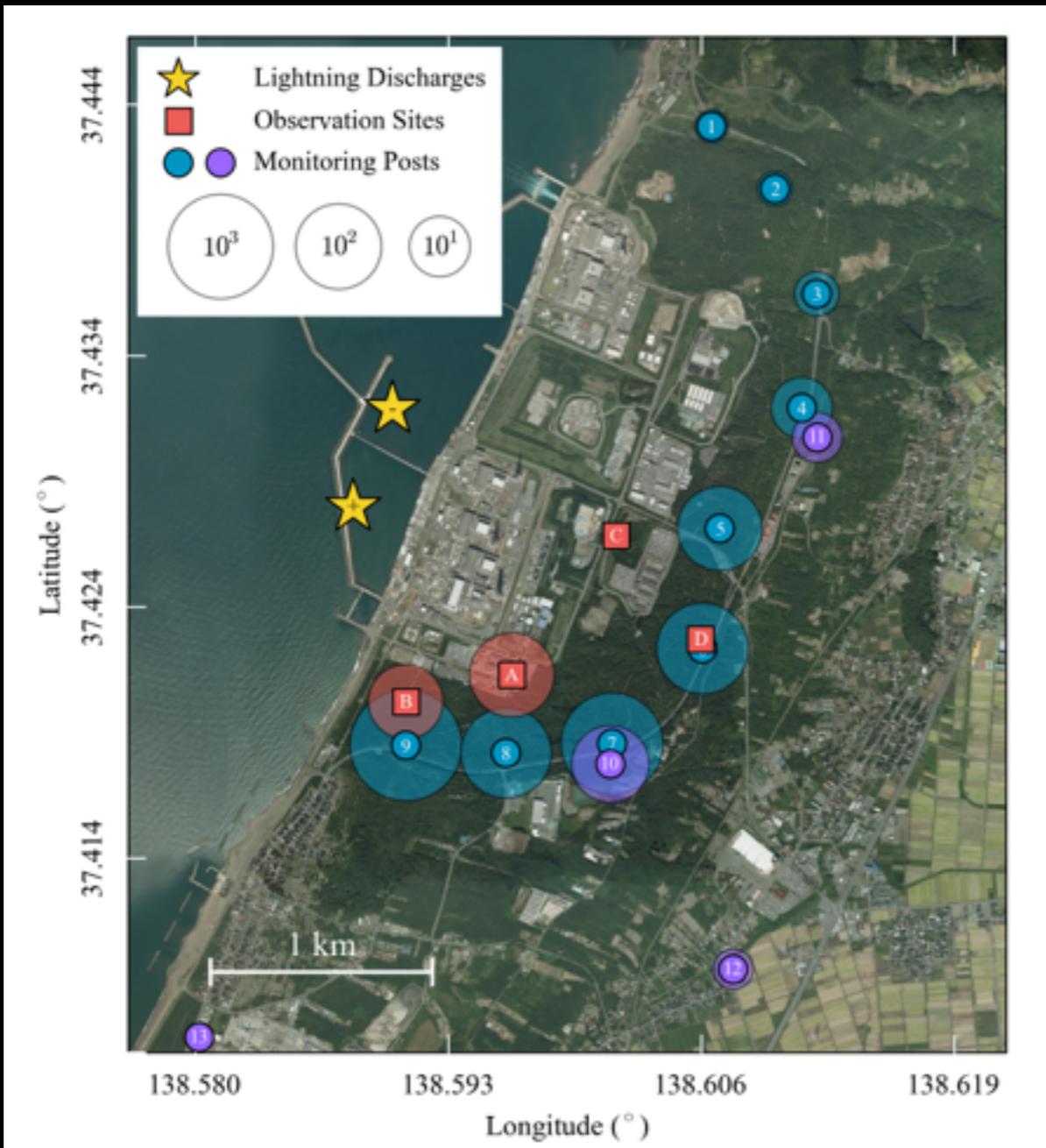
Maximum energy (~10 MeV) is consistent with our observation

Electron Kinetic Energy (MeV)

(Gurevich et al., Phys. Lett. A, 165, 463, 1992)

# Gamma-rays Associated with Lightnings

Spiky radiations (<0.1 s) detected coincidence with lightning discharges.  
(Example) 2017 February 6, 17:34 JST at the Kashiwasaki site



- Similar spiky event was previously detected on 2012 January 13 (Umemoto et al., 2016)
  - A positron-electron annihilation line at 511 keV was detected during the mysterious 2012 event.

We have detected 12 radiation events (including two short spiky events) in FY2016, already amounting to 32% of the total events since 2006.

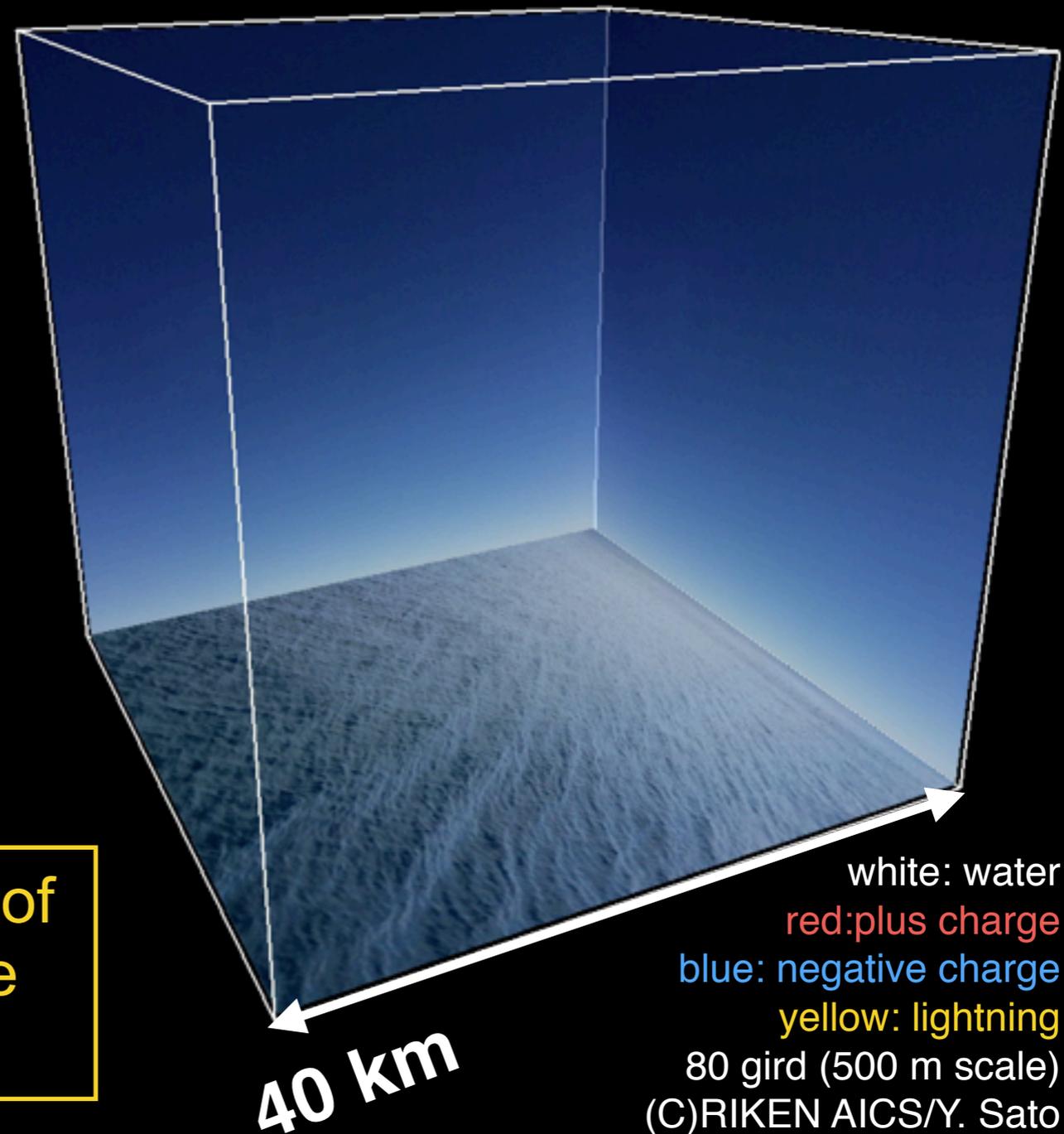
# Future Plan of Our GROWTH Collaboration

Our group is building a new multi-point observation network along the Japan sea based on radiation measurement techniques of the X-ray astronomy.

Observation will be compared with numerical simulation of thunderstorms

- Yousuke Sato (RIKEN/AICS→Nagoya Univ.) has implemented lightnings to meteorological simulation library SCALE (Scalable Computing for Advanced Library and Environment) for thunderstorms.
- We also developed Geant4 Monte Carlo simulation of gamma-ray propagation in the atmosphere (lead by Y. Furuta).
- The number of observation site will increase in FY2017 (at least additional 3).
- Electric field monitoring will be added via our interdisciplinary collaboration.

We will tackle to resolve the condition of the electron acceleration in Japanese winter thunderstorms.



# Summary

1. Strong and low-altitude winter thunderstorms along the Japan sea provide a unique opportunity to directly detect Bremsstrahlung gamma-rays from relativistic electrons accelerated in electric fields.
2. We developed a new portable, stand-alone, and low-cost gamma-ray detector and installed 10 observation points in 4 areas along the Japan Sea to trace moving thunderstorms.
3. We successfully detected 12 radiation during FY2016 winter including 10 prolonged gamma-ray events from thunderstorms and 2 short spiky events associated with lightning discharges.

see also talk by Wada @MIS18-05, 5/22 (today) 11:45 AM-12:00 PM



**We are planning a workshop in Japan for the high-energy atmospheric physics (support by ICRR).  
We welcome domestic and international collaborations for winter thunderstorm observations.**

