Multipoint Measurement Campaigns of Gamma rays from Thundercloud and Lightning in Japan

physicsworld TOP 10 BREAKTHROUGH 2017

Enoto et al., *Nature* 551, 481 (2017); Wada et al., GRL (2018) in press

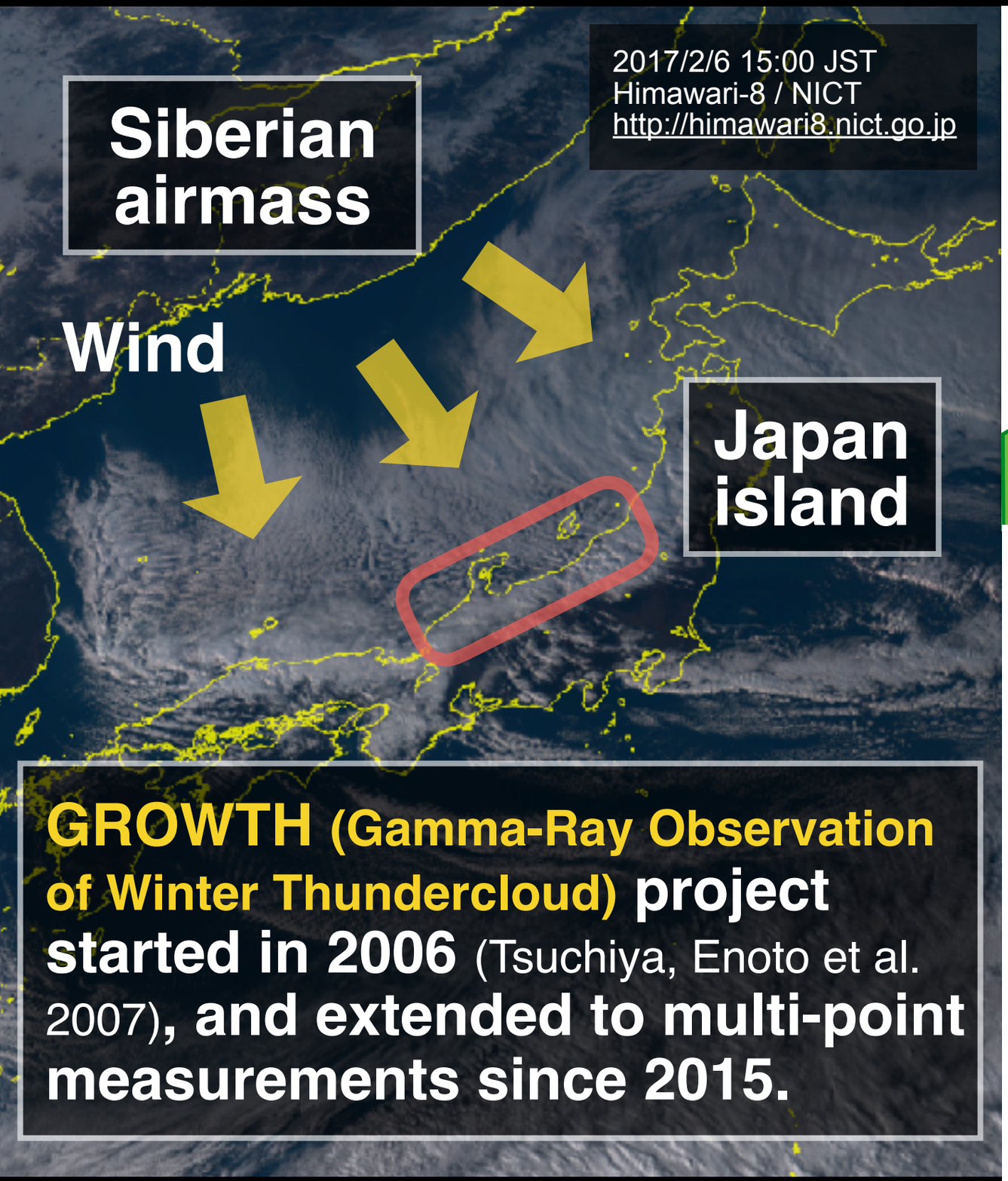
Teruaki Enoto, Yuki Wada, Yoshihiro Furuta, Kazuhiro Nakazawa, Takayuki Yuasa, Kazufumi Okuda, Kazuo Makishima, Mitsuteru Sato, Yousuke Sato, Toshio Nakano, Daigo Umemoto, Harufumi Tsuchiya, Masashi Kamogawa, Gregory Bowers, David Smith Takeshi Morimoto, and Yoshitaka Nakamura (*Kyoto University, The University of Tokyo, RIKEN, Nagoya University, Hokkaido University, JAEA, Tokyo Gakugei Univ., Los Alamos National Laboratory, Univ. of California, Kindai Univ., and Kobe City College*)

Photo at Fukui, Japan by Otowa Electric Co., Ltd. / Masako Tanaka

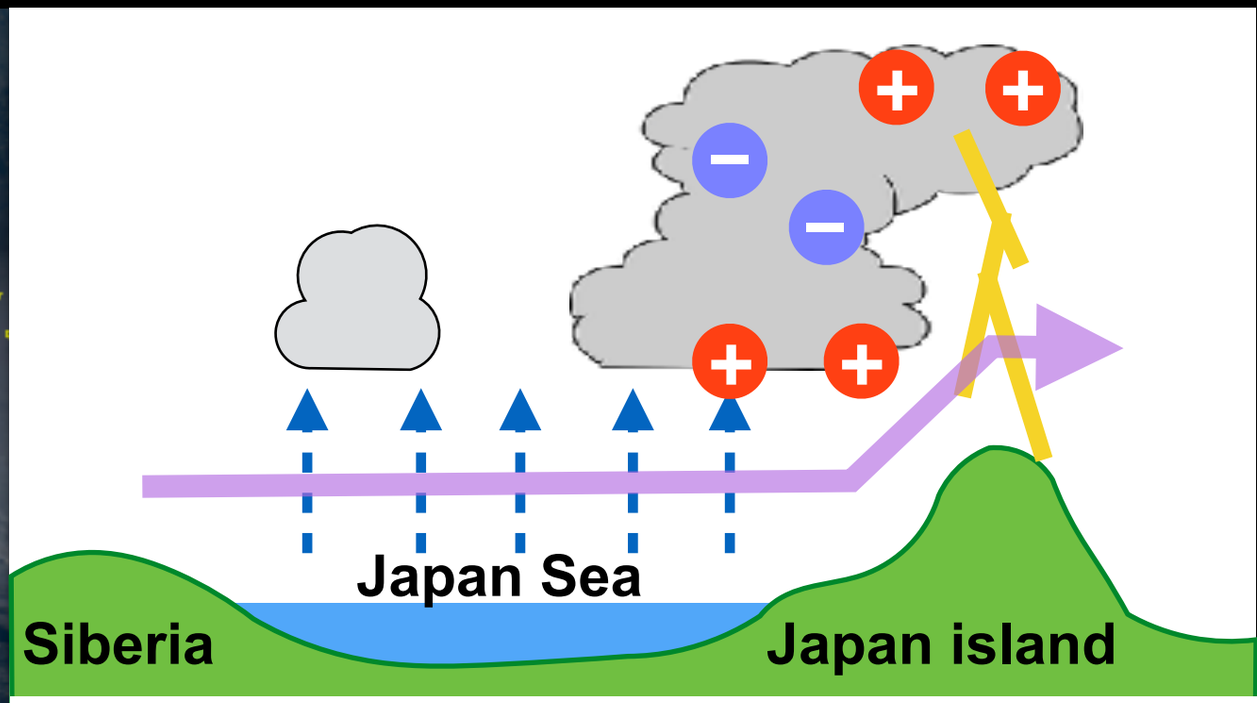
12:30-12:45 (O-11-07) June 22 (Friday), 12+3 minutes, International Conference on Atmospheric Electricity (ICAE) at Nara

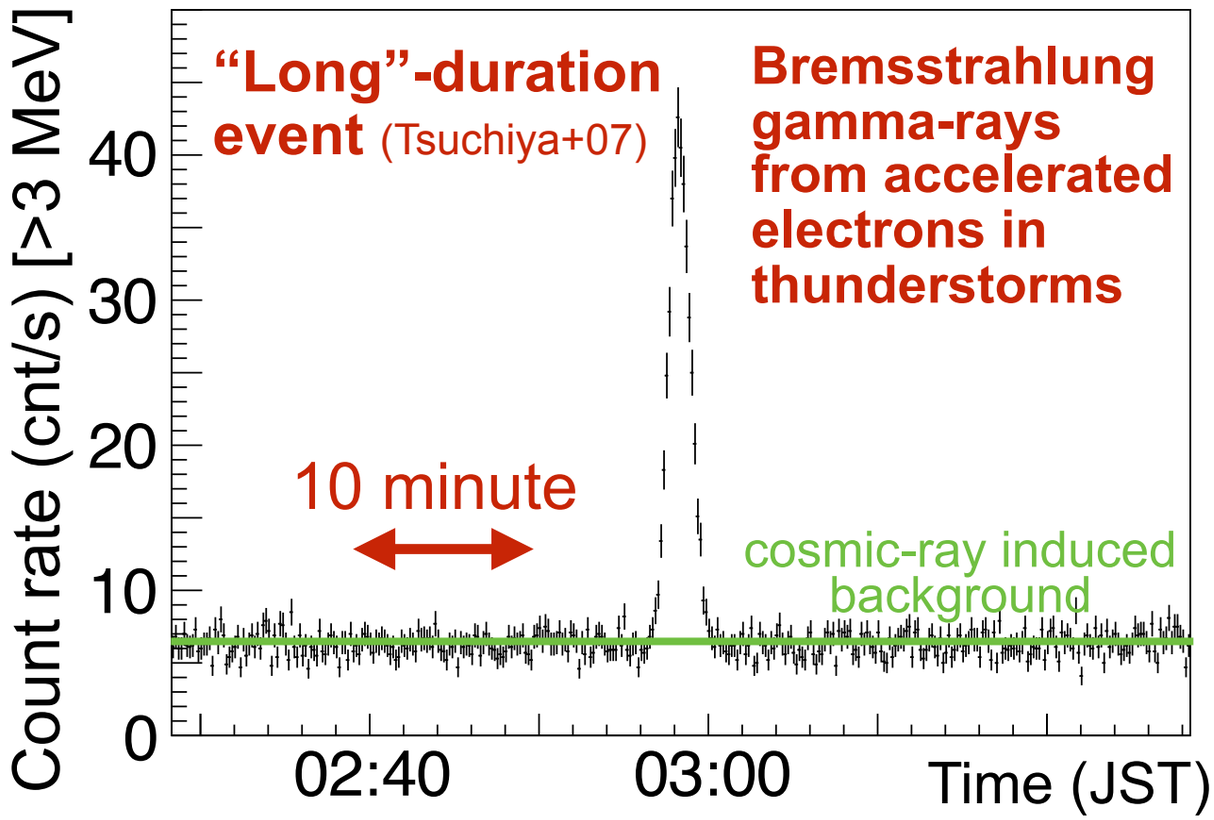
Winter thunderstorm and lightning in Japan

low altitude (<1 km), powerful lightning, frequent positive discharge
Ideal for observing the high-energy atmospheric phenomena



GROWTH (Gamma-Ray Observation of Winter Thundercloud) project started in 2006 (Tsuchiya, Enoto et al. 2007)**, and extended to multi-point measurements since 2015.**





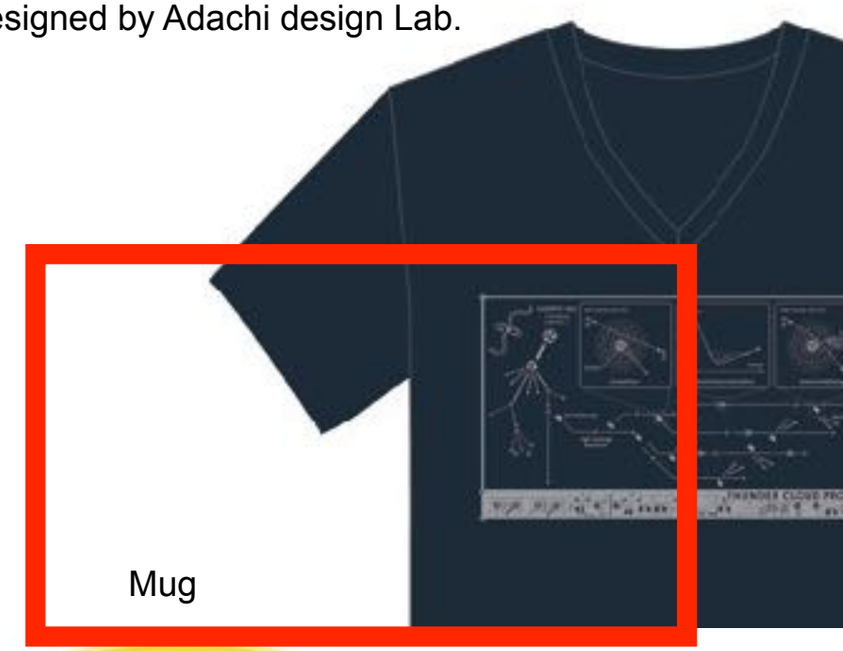
Supported by Academic Crowdfunding

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
季の雷を思い出しま
応援しています。

Original Return (Reward)

designed by Adachi design Lab.



Mug

Original T-shirt

Acknowledgement & USB

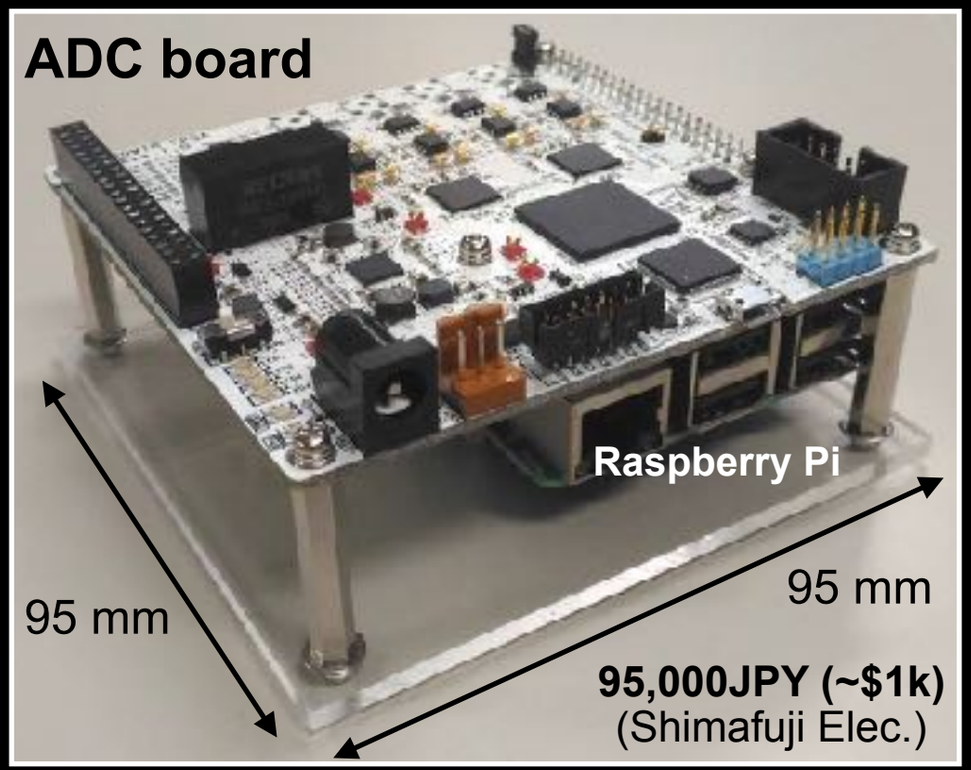
At the initial phase of our project, citizen supporters financially helped us through the academic crowdfunding. The donation gathered during the two month was ~$16k from 153 contributors. This has been used for prototype manufactures and preparing for power-plugs on the high school roofs.

Thank you for your support :)

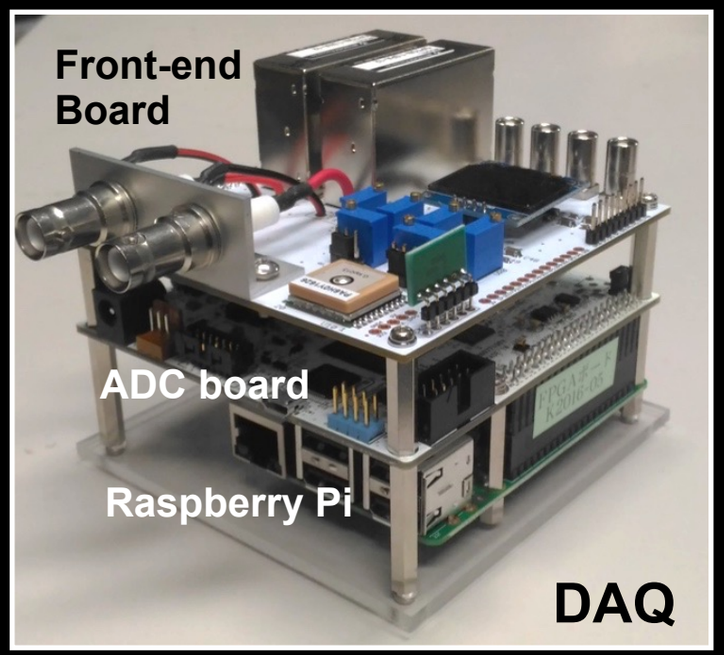
Since 2015, our project has been supported by the crowd funding “academist”, Grants-in-Aid for Young Scientists (A) Kakenhi 16H06006, the SPIRITS program of Kyoto University, and the joint research program of the ICRR, University of Tokyo.

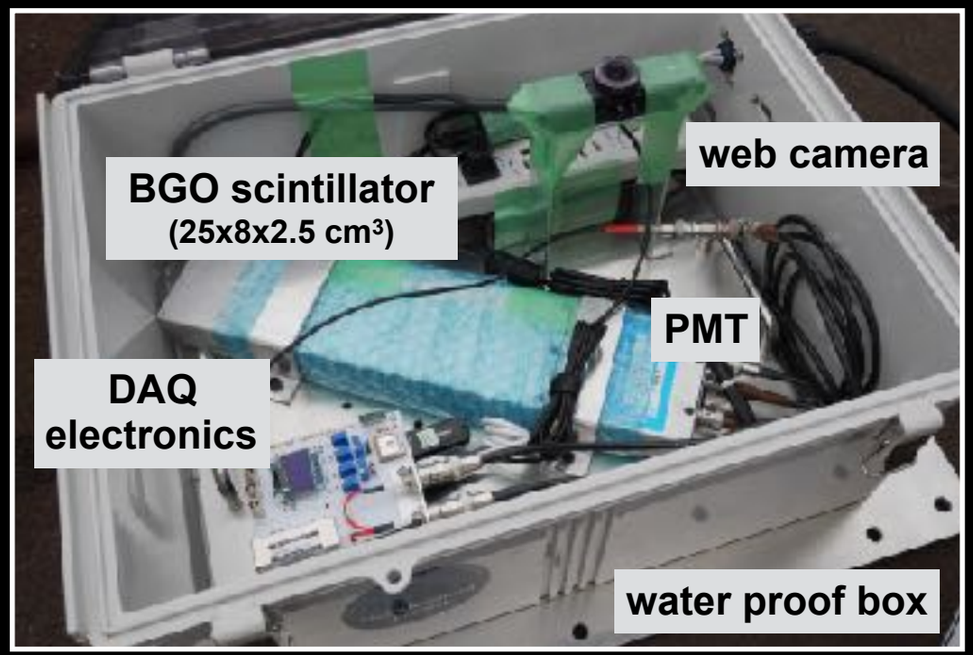
Radiation detectors for mapping observations

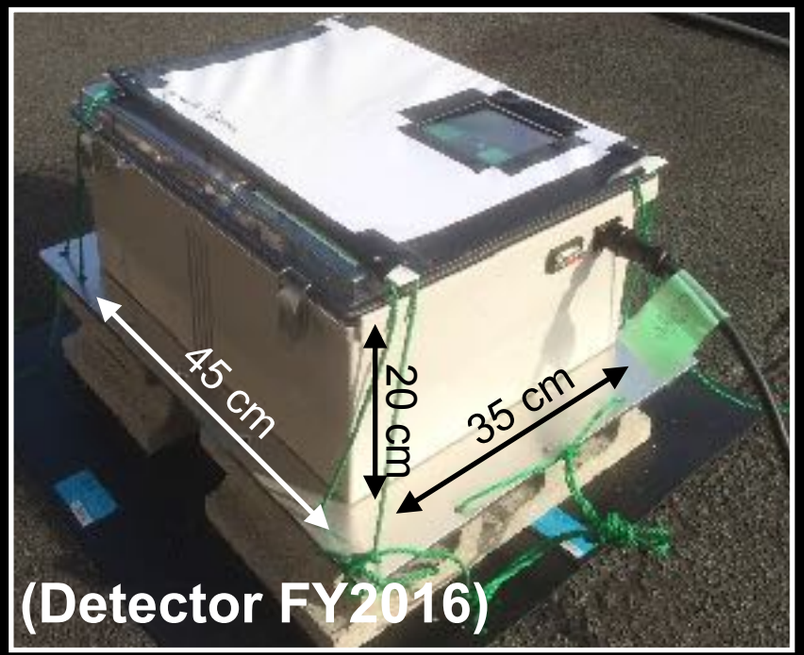
A new stand-alone, low cost, and high-performance data acquisition (DAQ) system was developed; e.g., FPGA board of 4 channel 50 MHz, 12 bit ADC



- Gamma-rays detected with BGO scintillators
- Recorded with energy and GPS time tag
- Environmental sensors (temperature, pressure, etc)
- Mobile data transfer & remote control
- Deployed at local high schools, universities
- Compatible with CubeSats, and aiming at distributing to citizen scientists

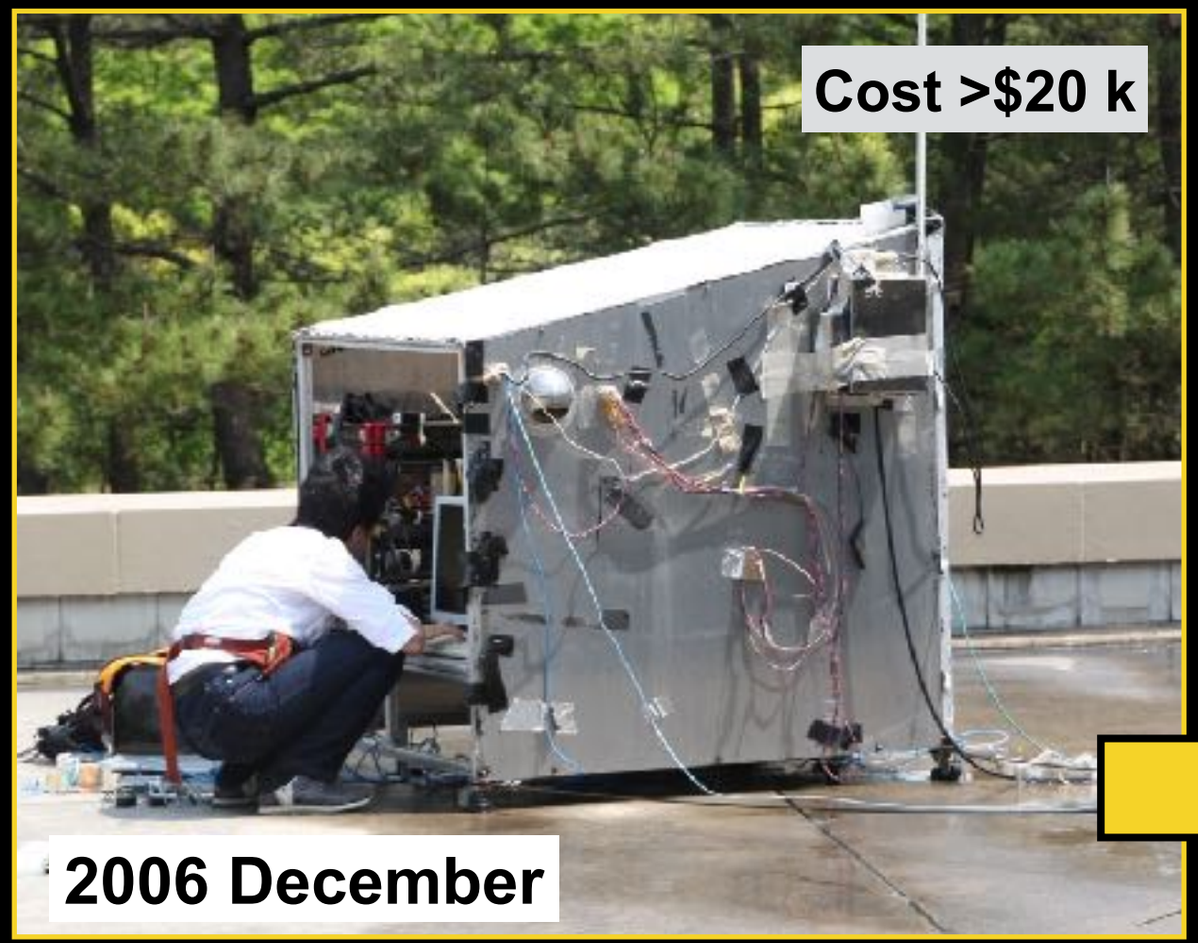


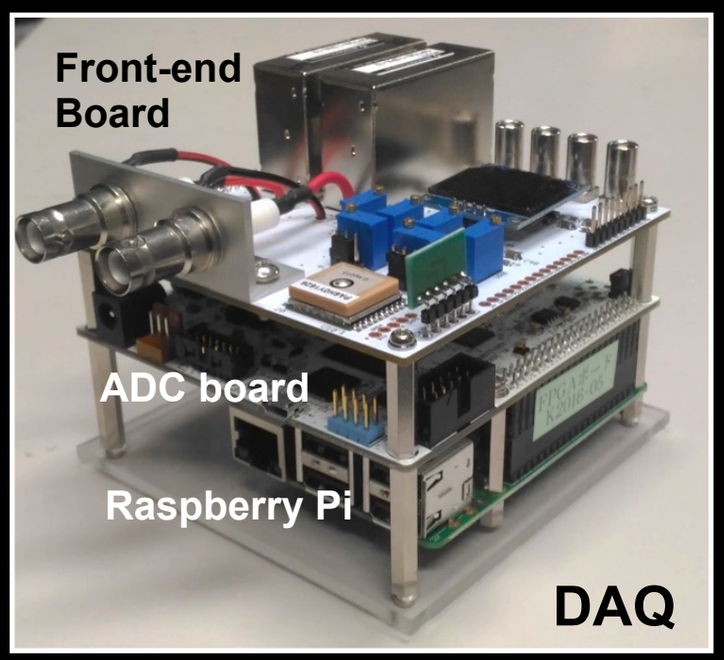


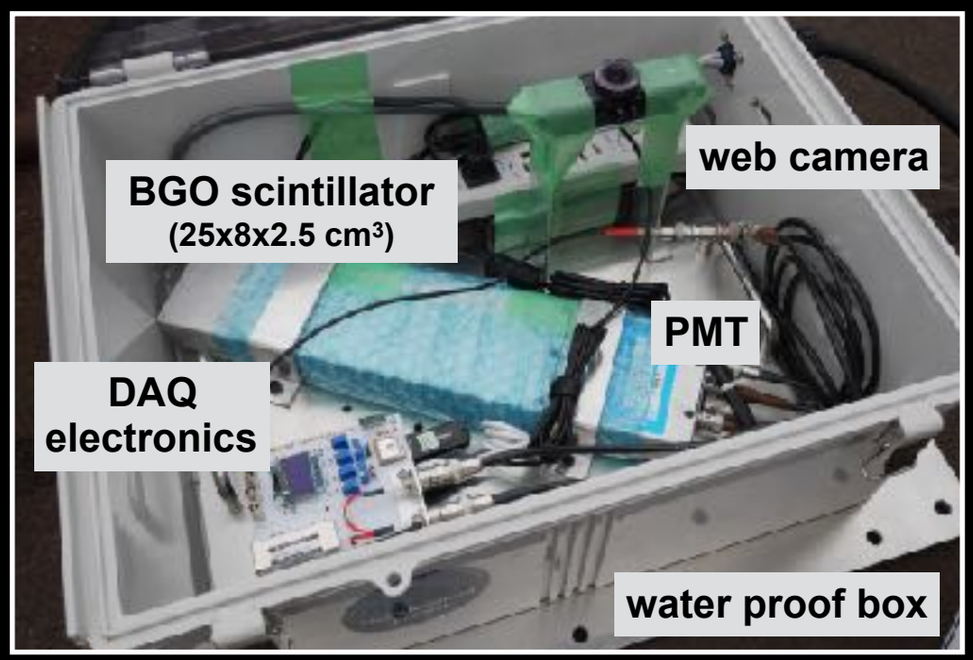


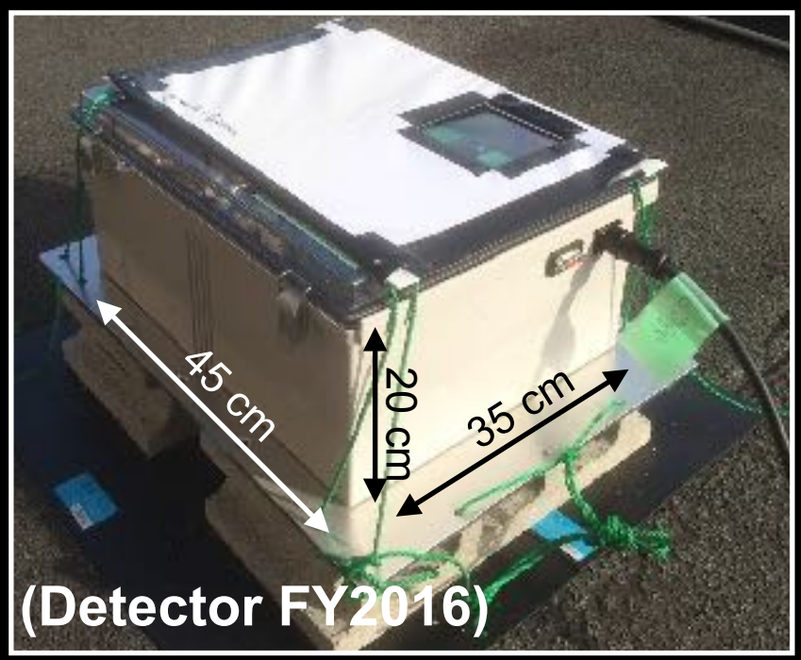
Wada, Master thesis of the University of Tokyo, “Construction of the multi-point observation network for thundercloud gamma-rays”
(ref) FPGA/ADC board specification http://ytkyk.info/blog/2016/09/04/growth-fpga-adc-board/ (C) T. Yuasa

Radiation detectors for mapping observations









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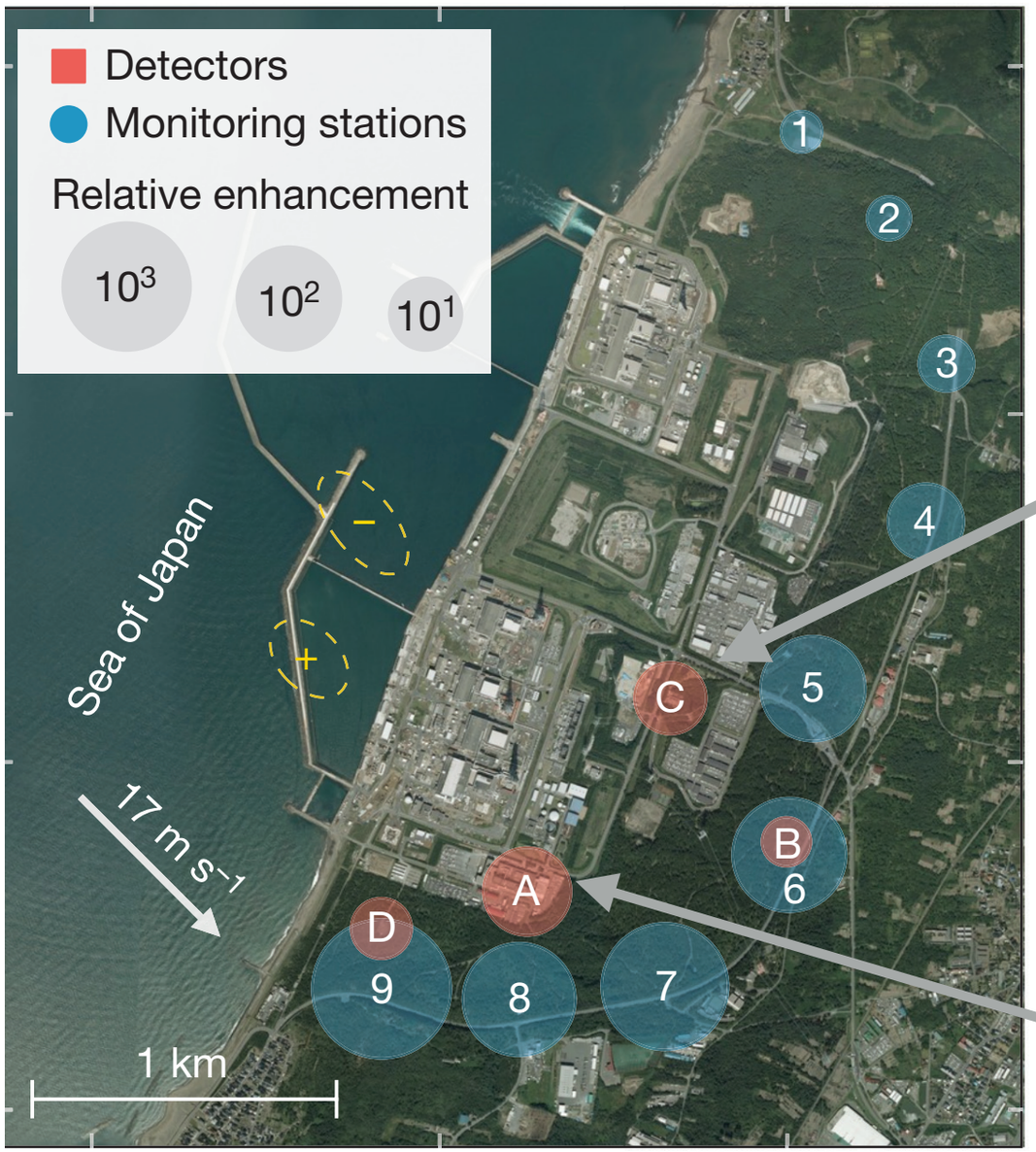
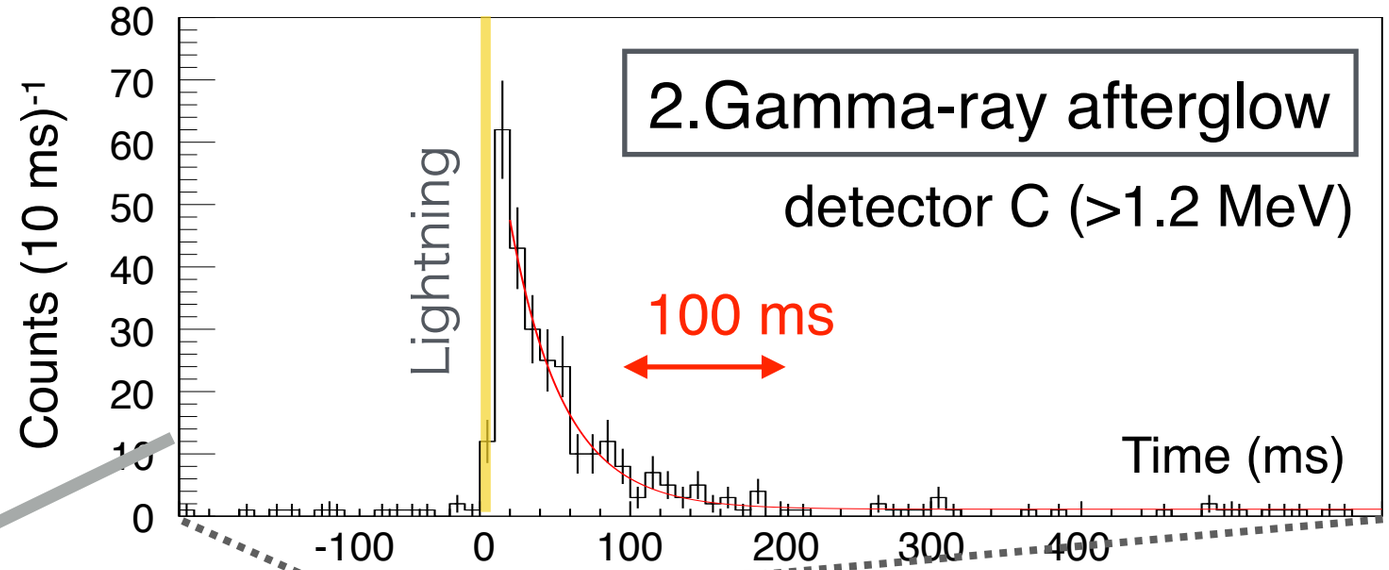
Enoto, Wada et al., *Nature* 551, 481 (2017)

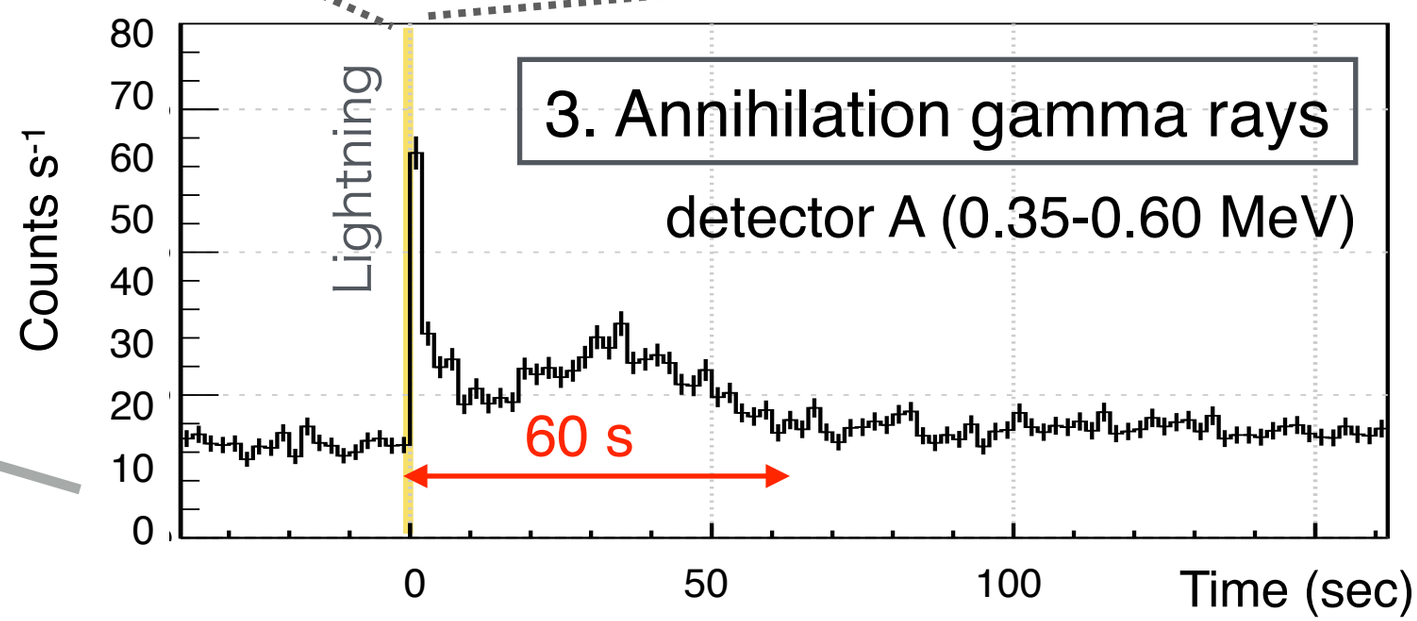
Short-duration burst associated with lightning

on February 6, 2017, 17:34:06, at Kashiwazaki station had three components

1. **Intensive initial spike** (<~a few milliseconds, exceeds 10 MeV)
2. **Gamma-ray afterglow** (<~100 ms, <10 MeV)
3. **Delayed annihilation gamma rays** (~minute, at 0.511 MeV)







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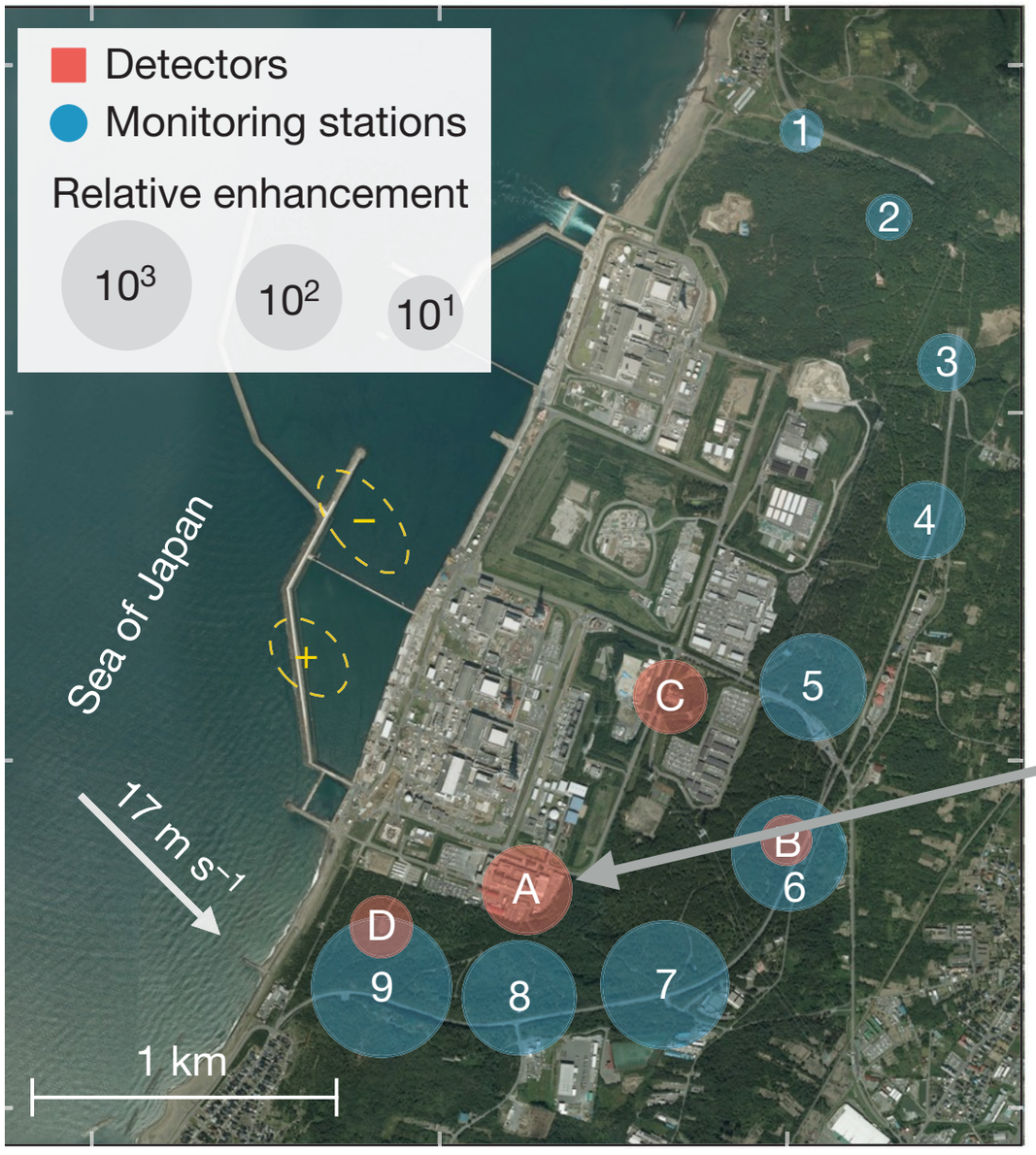

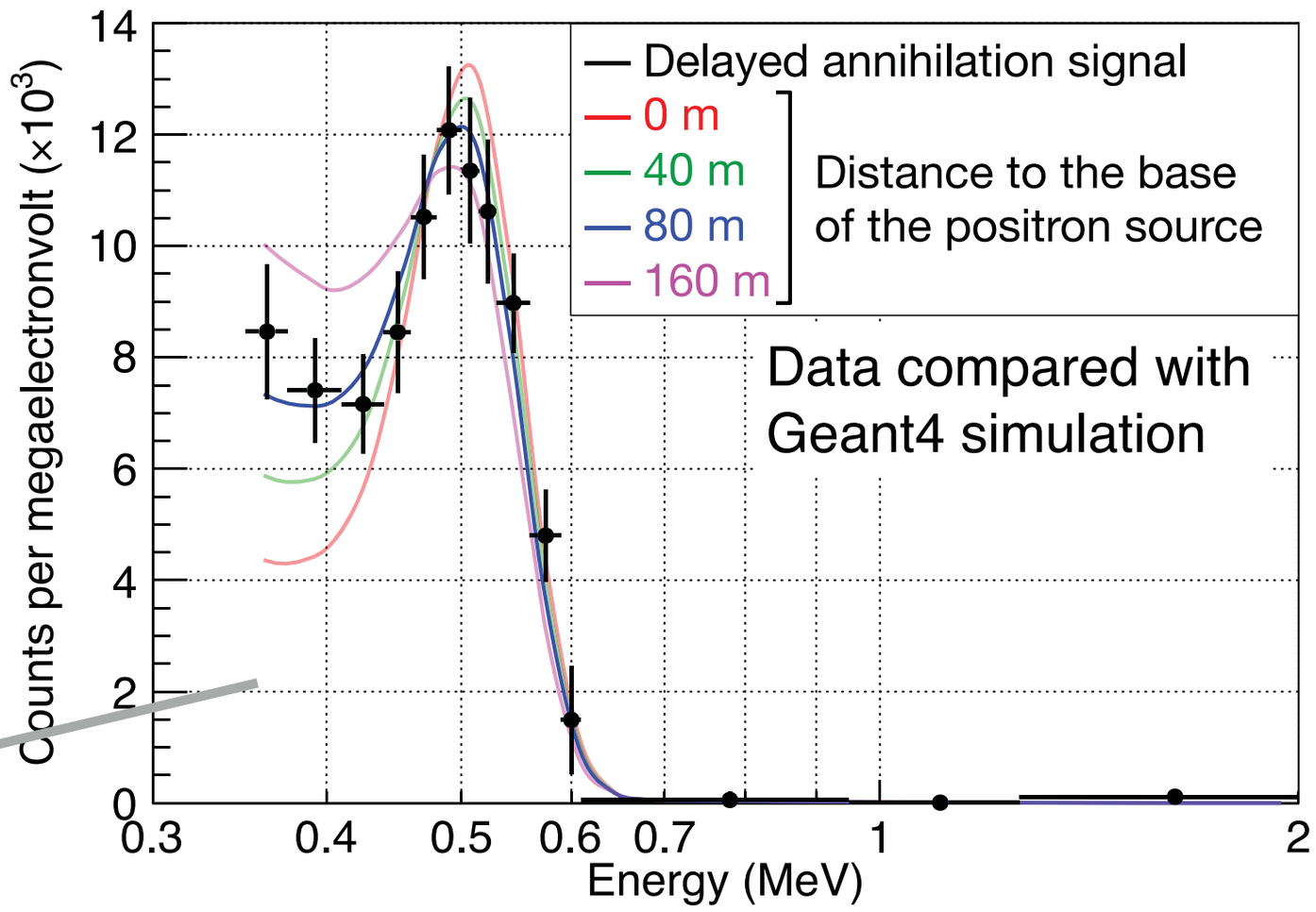

We detected evidence for the annihilation signals at 0.511 MeV ~35 sec after the lightning.

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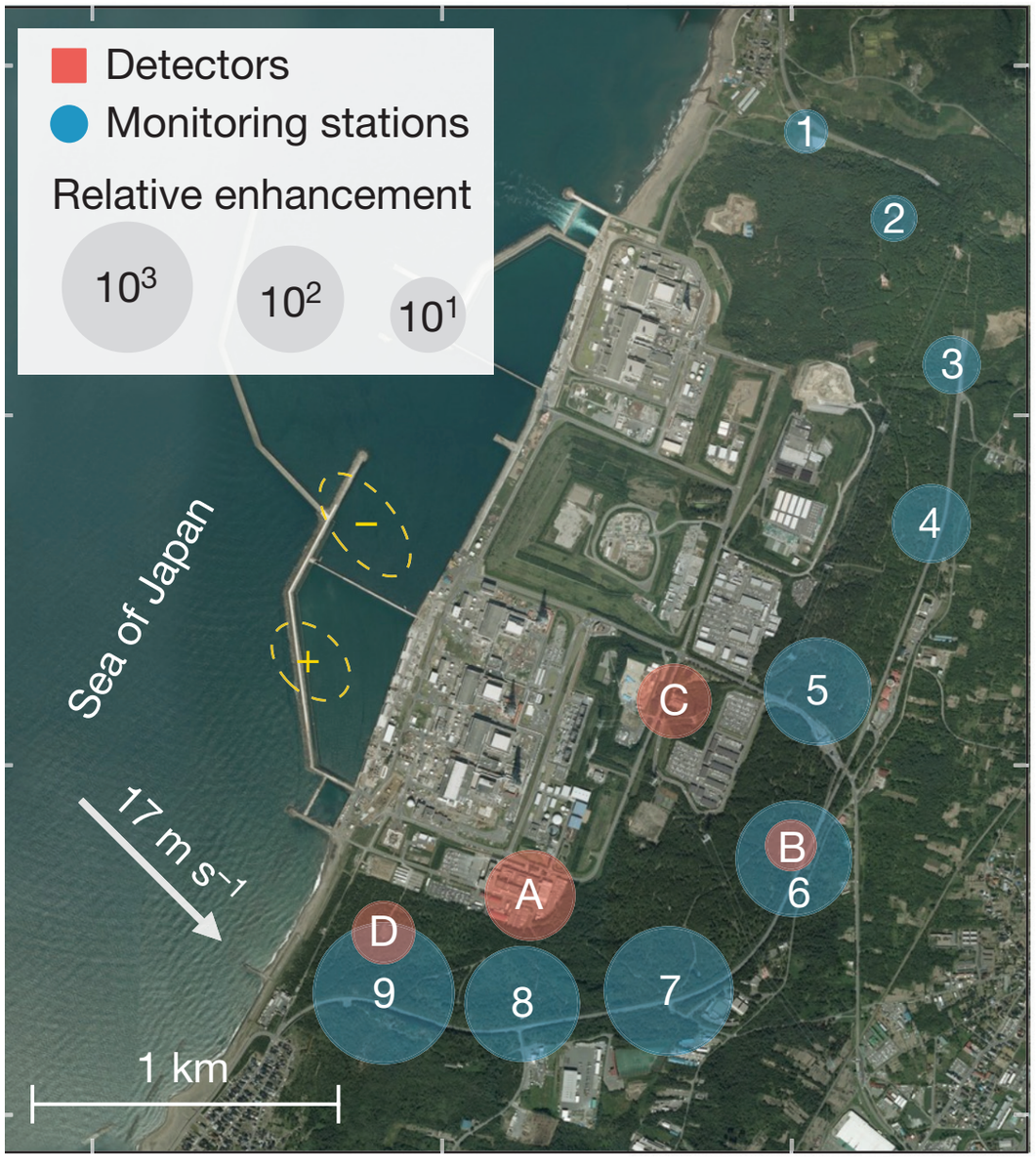
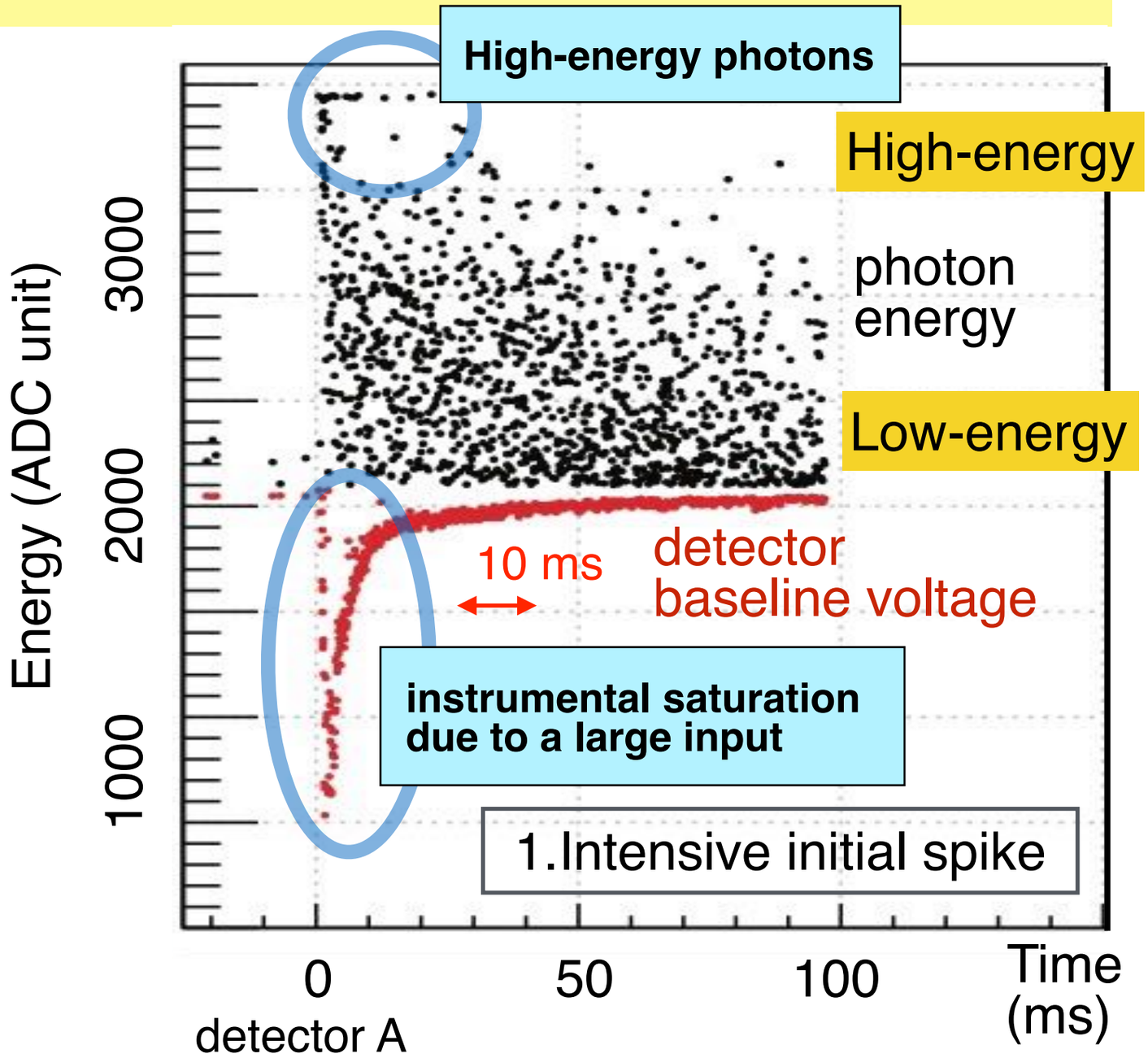




Photonuclear reactions triggered by lightning

downward TGF (initial spike)

half-life 10 min

γ-rays

atmospheric **nitrogen** ^{14}N

radioactive isotope ^{13}N

neutrino

carbon isotope ^{13}C

proton 7
neutron 7

proton 7
neutron 6

proton 6
neutron 7

fast neutron

positron

photonuclear reaction

beta-plus decay

$\gamma + {}^{14}N \rightarrow {}^{13}N + n$

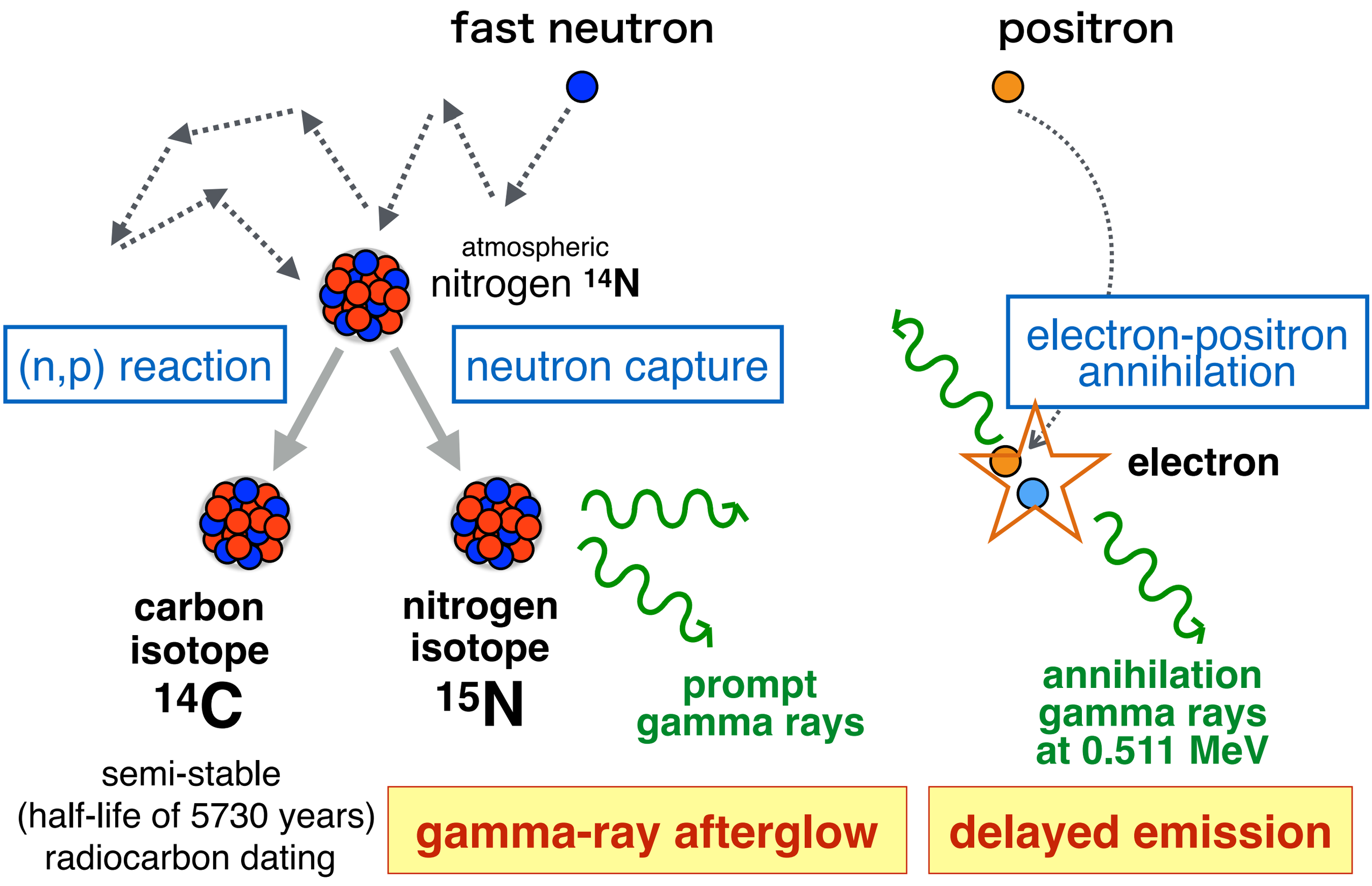
${}^{13}N \rightarrow {}^{13}C + e^{+} + \nu$

$(p \rightarrow n + e^{+} + \nu)$

fast neutron

positron

Gamma rays from neutron and positrons



Discussion

Enoto, Wada et al., *Nature* 551, 481 (2017)

1. **Initial flash:** ~a few ms, extremely bright => Downward TGF?

2. **Neutron signal [γ-ray afterglow]** (see also Bowers et al. 2017)

   a. Observed exponential decay constant of 40-60 ms is consistent with the prediction ~56 ms of the neutron atmospheric thermalization.

   b. Spectrum with a sharp cutoff at 10 MeV is well explained by prompt gamma rays from nitrogens and surrounding materials.

3. **Positron signal [annihilation signal]** (see also Umemoto et al. 2016)

   a. The ~35 sec delay from lightning is consistent with the wind flow.

   b. Relative intensity of the 0.511 MeV emission line and continuum below it gives a distance to the base of the positron-emitting cloud: ~80 m

   c. Estimated number of neutron 4×10^{12} produced by photonuclear reaction is within predicted range of $10^{11\text{-}15}$ (Babich+10, Carlson+14).

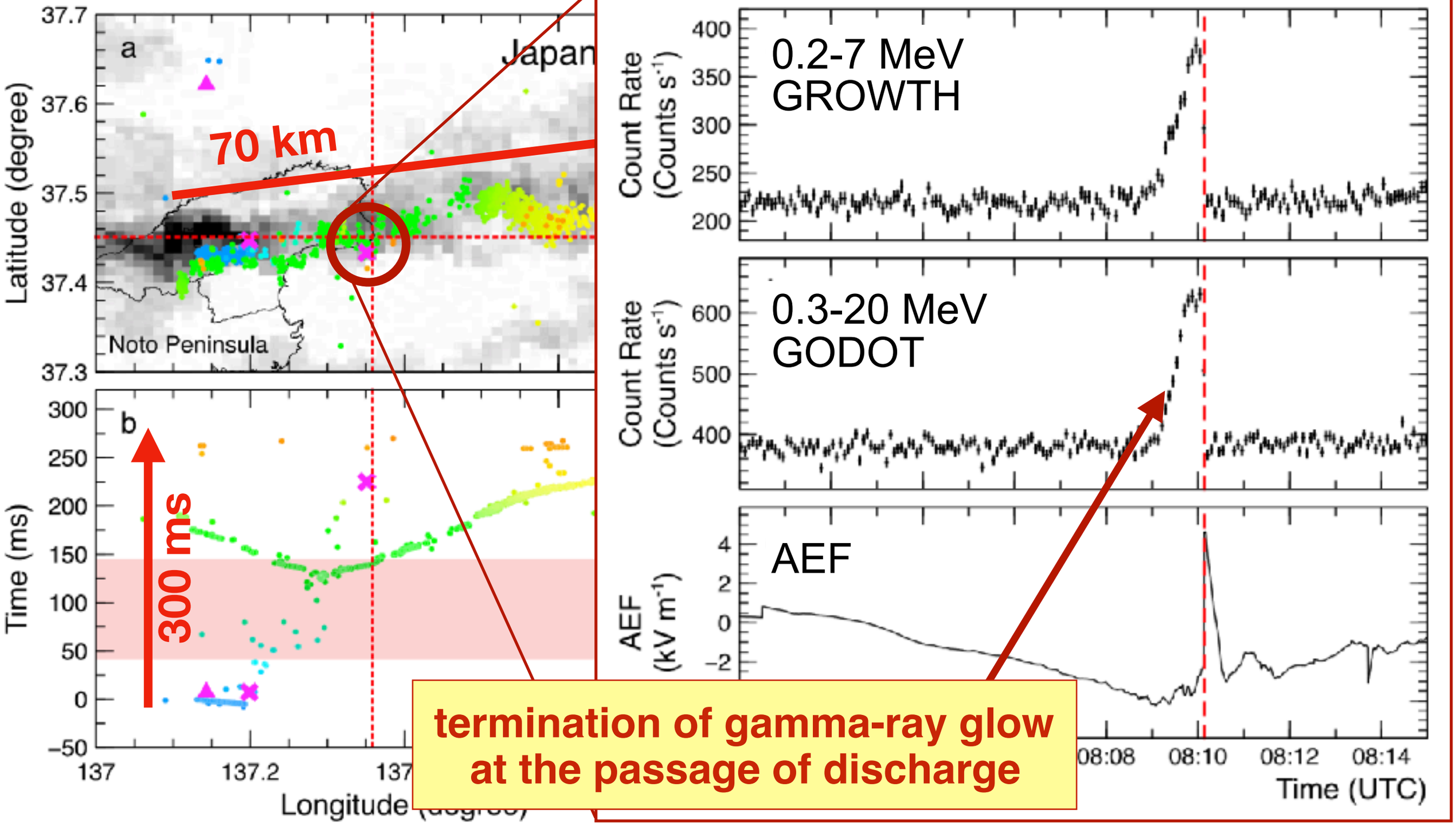
4. **Lightning produces atmospheric ^{13}N, ^{15}N, ^{13}C, & ^{14}C isotopes.**

(See also, Babich+07, Rutjes+2017)

Wada, Bowers et al., *Geophys. Res. Lett.*, 48 (2018)

Lightning terminated electron acceleration

gamma-ray glow stopped at the lightning on February 11, 2017, at Suzu.



Wada, Bowers et al., *Geophys. Res. Lett.*, 48 (2018)

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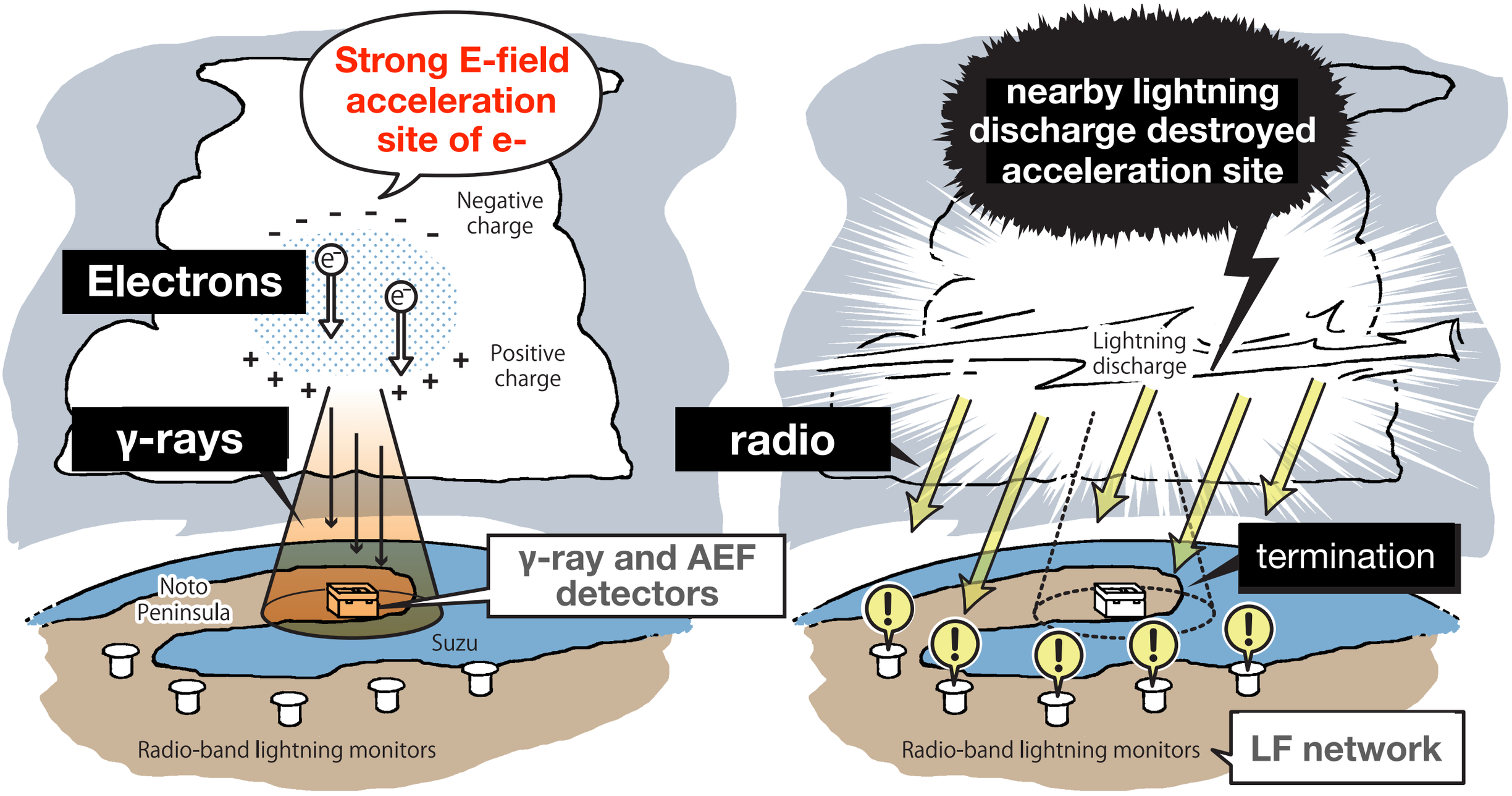
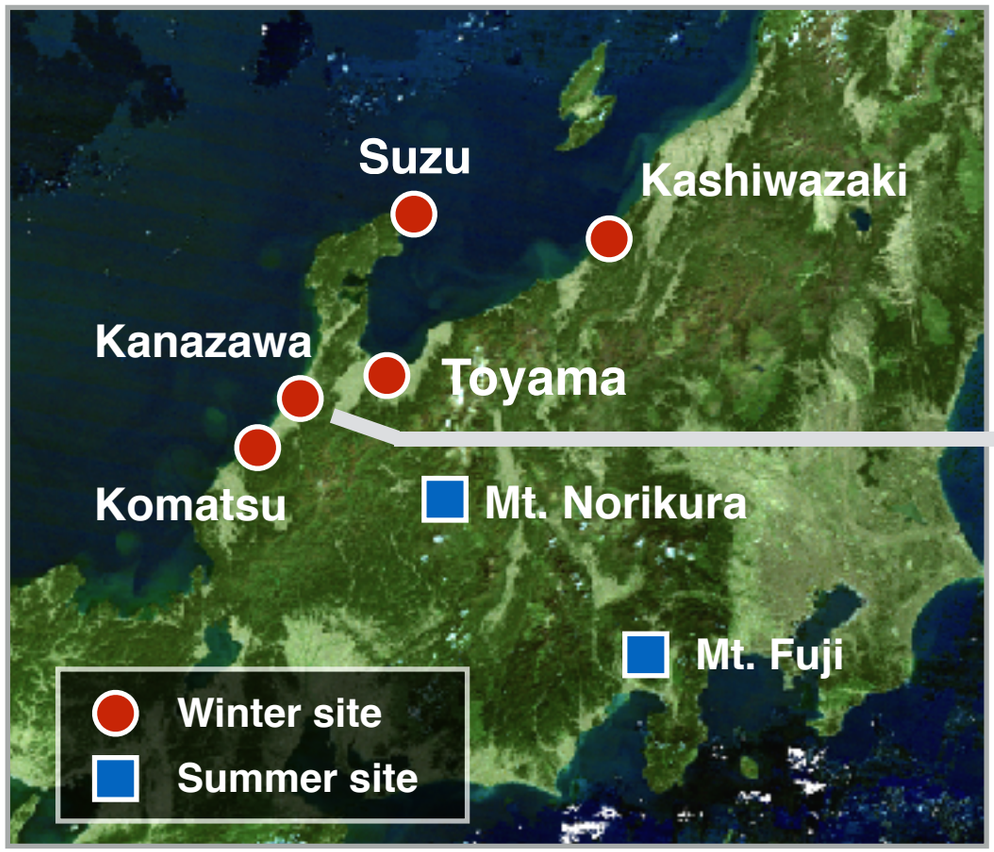


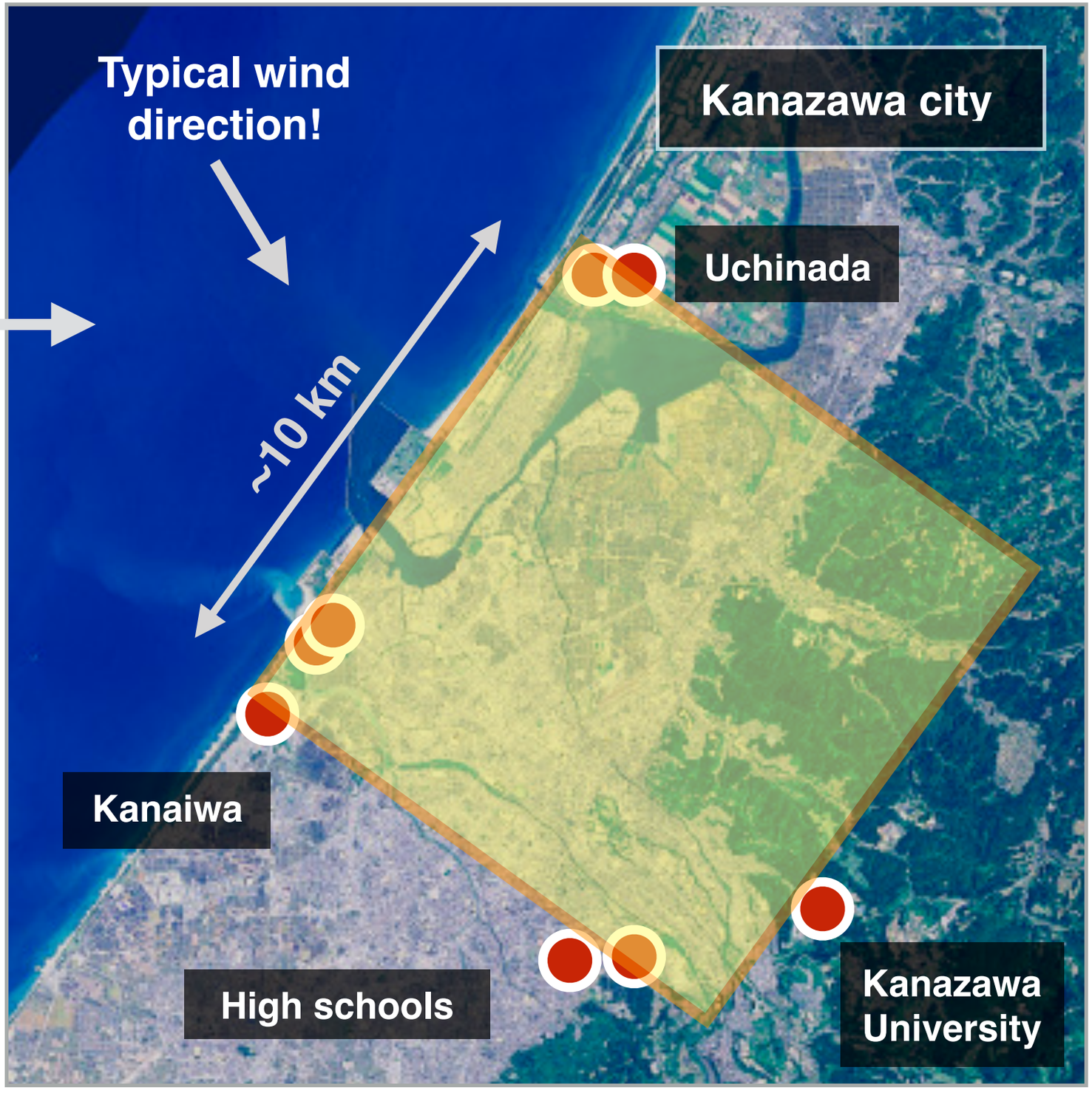
Collaboration of γ-rays GROWTH and GODOT (Smith & Bower team), AEF (Kamogawa team), LF network (Morimoto team)

Wada, Bowers et al., *Geophys. Res. Lett.*, 48 (2018)

Multi-point γ-ray Measurement Campaign

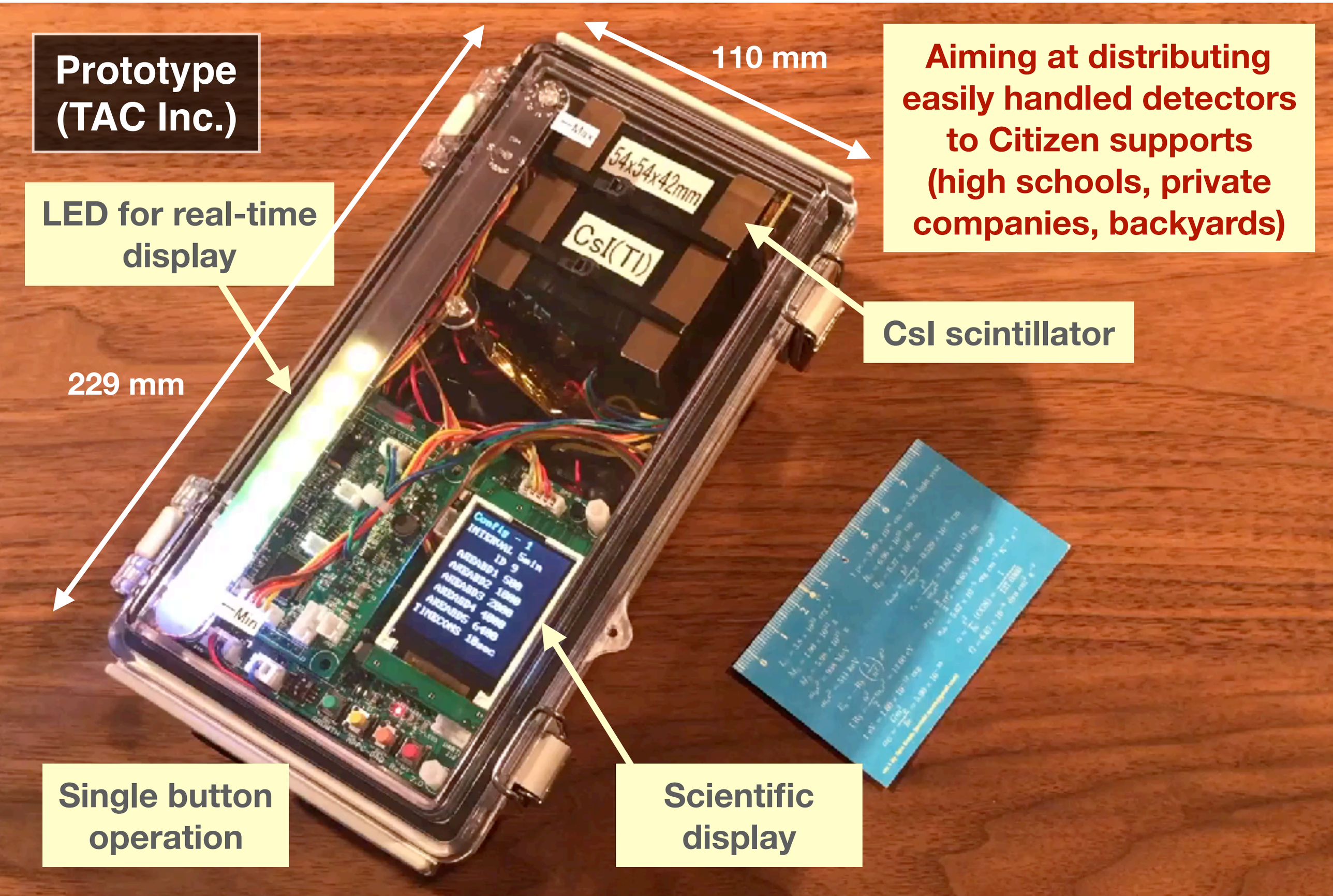
Trace thundercloud for statistical study of gamma-ray glow & downward TGF





Difficulty to obtain sites and deployment — Citizen science approach?

Portable detector for “open” citizen science



Conclusion

Selected as one of the Top 10 Physics Breakthroughs of 2017 by Physics World magazine, IOP Publishing Ltd

- **Powerful winter thunderstorms and lightning in Japan are ideal for observing high-energy atmospheric phenomena.**
- **Gamma-ray Observation of Winter Thunderstorm (GROWTH) collaboration started multi-point campaigns since 2015.**
- **We detected signals of neutrons and positrons produced by photonuclear reactions triggered by a lightning discharge.**

Enoto, Wada, Furuta et al., *Nature* 551, 481 (2017)

- **We observed termination of the gamma-ray glow associated with lightning via radio, AEF, and radiation measurements.**

Wada, Bowers, Enoto et al., *Geophys. Res. Lett.* 45, (2018)

- **We are aiming at establishing new mapping networks at Kanazawa as a citizen-supporting open science framework.**