

# High-Energy Radiation Phenomena from Winter Thunderstorms and Lightning In Japan

Enoto et al., *Nature* 551, 481 (2017); Wada et al., *GRL* 45, 11 (2018)

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(1) Kyoto University, (2) RIKEN, (3) JAEA, (4) Nagoya University, (5) Hokkaido University, (6) Univ of California Santa Cruz, (7) Tokyo Gakugei Univ, (8) Kobe City College of Tech., (9) Kinki University,



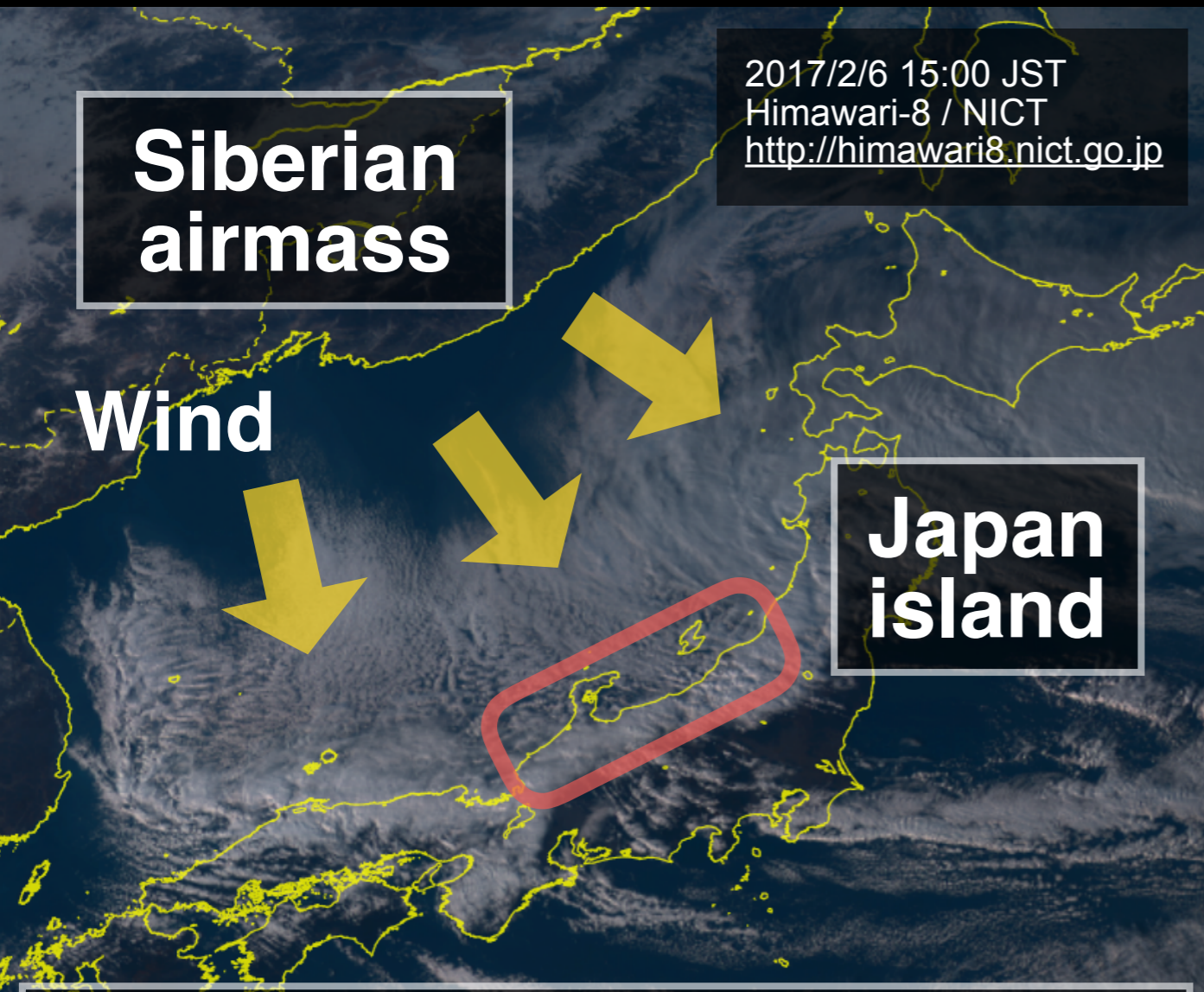
Photo at Fukui, Japan by Otowa Electric Co., Ltd. / Masako Tanaka

17:00-17:15, 11 December, 2018@American Geophysical Union (AGU) fall meeting, Energetic radiation from lightning and thunderstorm I (Room 201)

# Winter thunderstorm and lightning in Japan

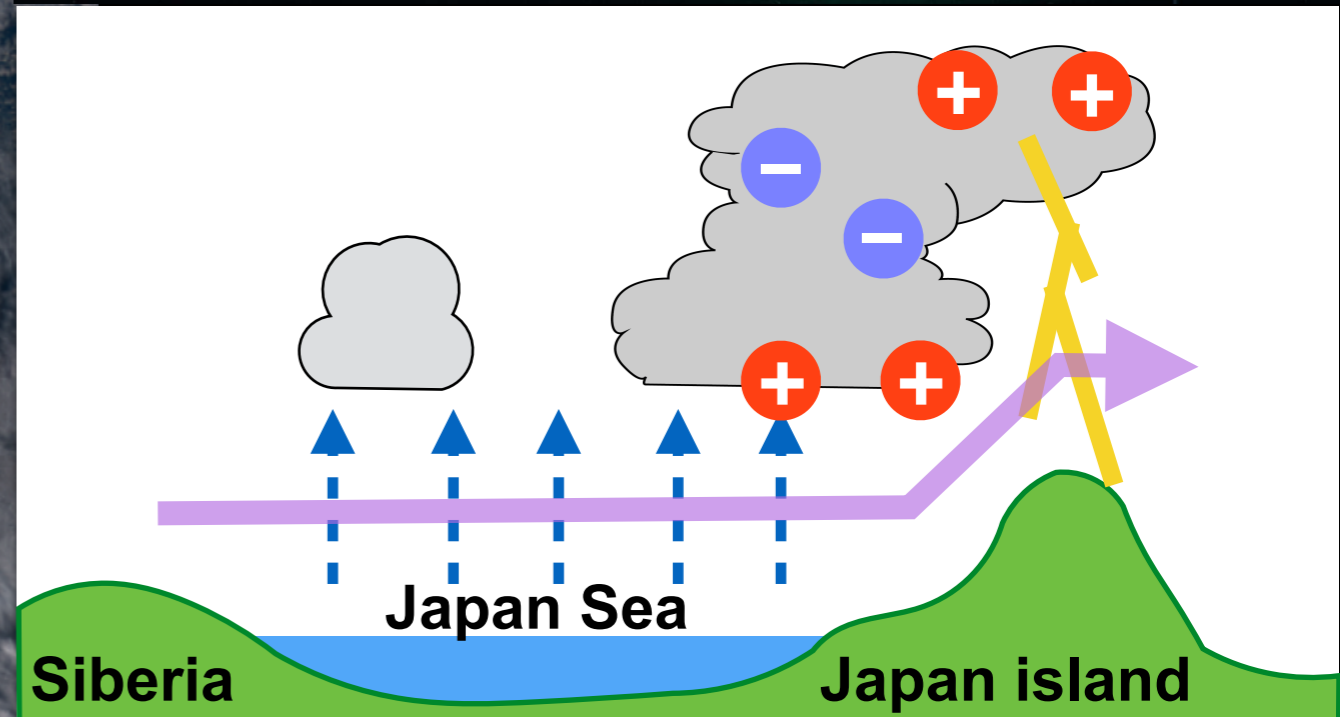
low altitude (<1 km), powerful lightning, frequent positive discharge

Ideal for observing the high-energy atmospheric phenomena



A winter lightning discharge in Japan (Fukui, Nov. 20, 2005)  
(C) Toshio Yoshioka and Otowa Electric Co., Ltd.

**GROWTH (Gamma-Ray Observation of Winter Thundercloud)** project started high-energy observations in 2006 (Tsuchiya, Enoto et al. 2007), and extended to multi-point campaigns 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)

## Original Return (Reward)

designed by Adachi design Lab.



Mug

Original T-shirt



Acknowledgement & USB

日本海沿岸に住んでいたことがあり、冬季の雷を思い出しました。とても興味深い研究だと思います。応援しています。

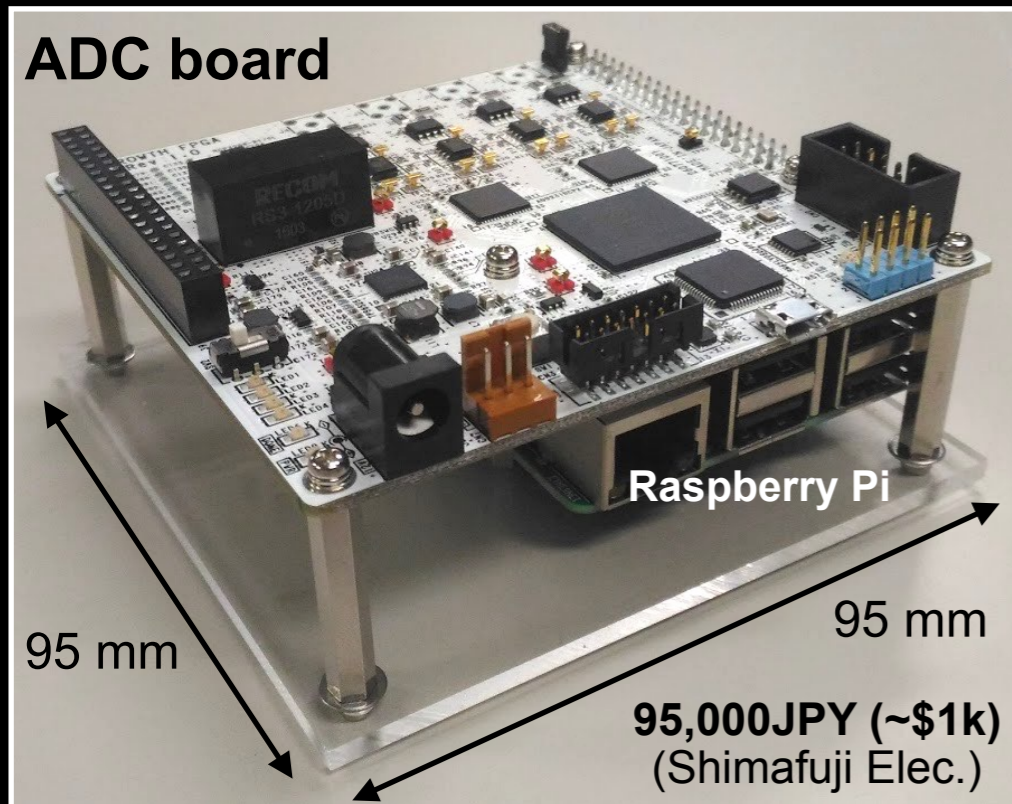
At the initial phase of our project, citizen supporters financially helped us through the academic crowdfunding. The donation gathered during the two month was ~\$16k from 153 contributors. This has been used for prototype manufactures and preparing for power-plugs on the high school roofs.

**Thank you for your support : )**

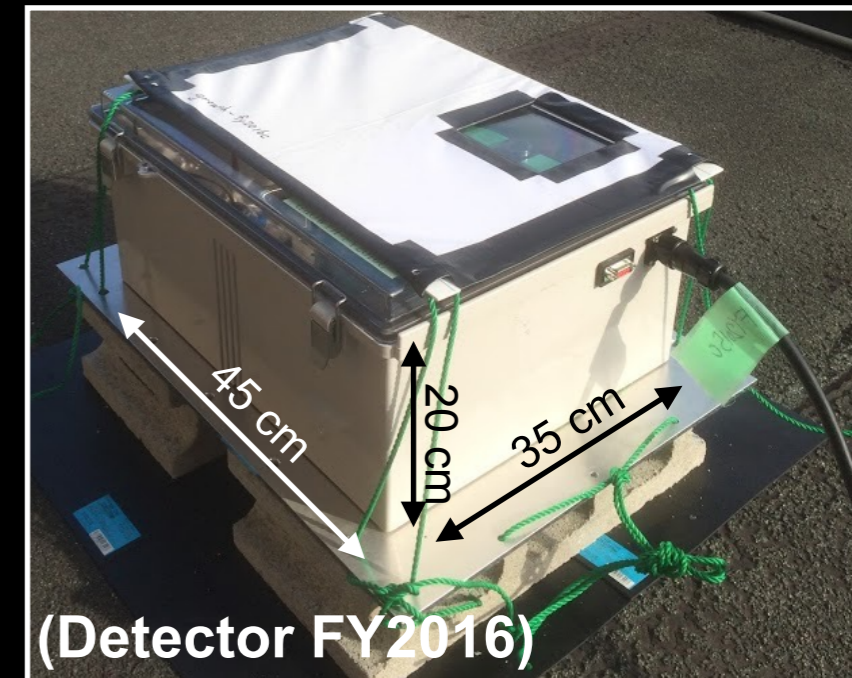
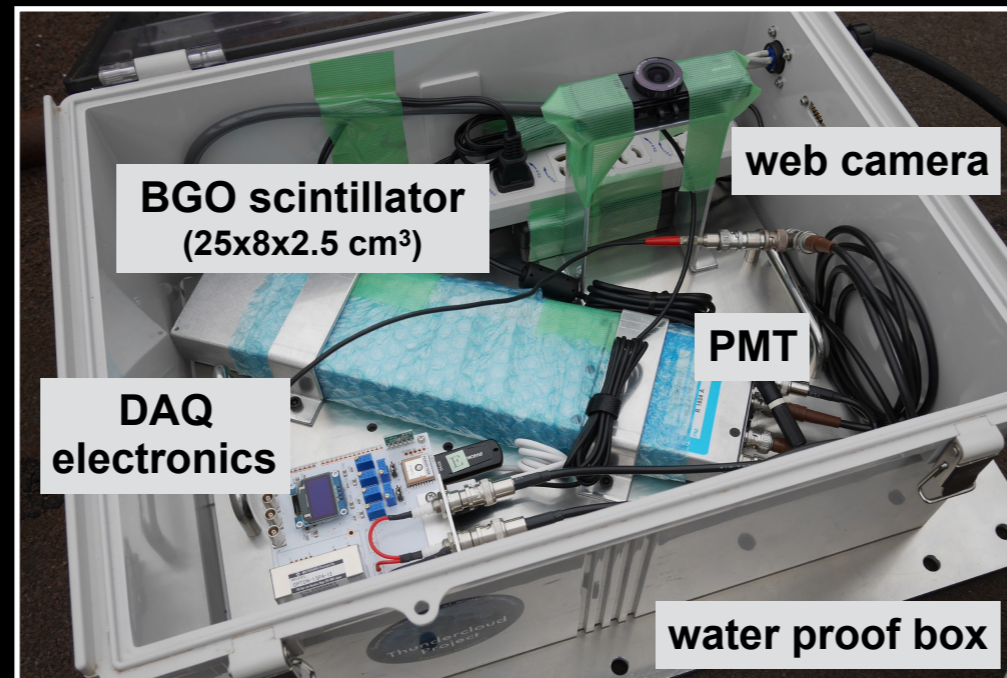
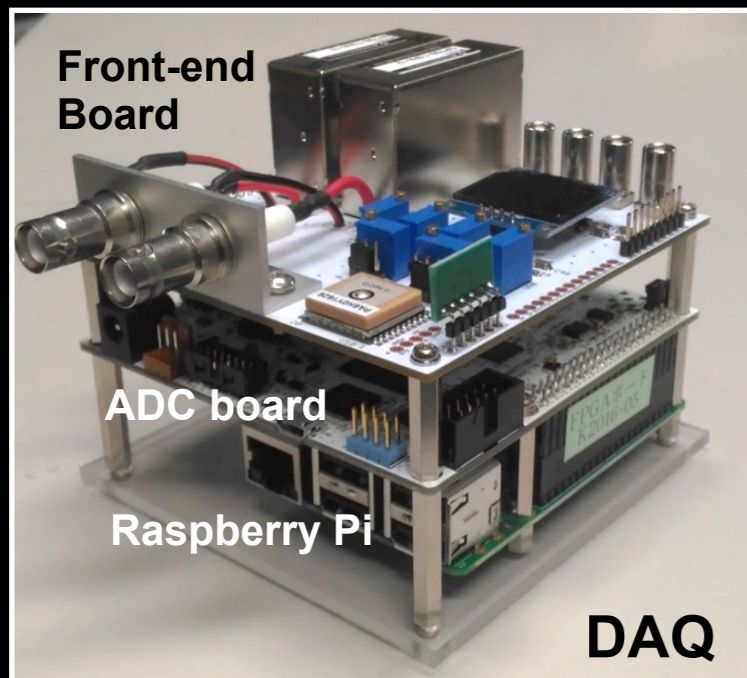
Since 2015, our project has been supported by the crowd funding "academist", Grants-in-Aid for Young Scientists (A) Kakenhi 16H06006, the SPIRITS program of Kyoto University, and the joint research program of the ICRR, University of Tokyo.

# Radiation detectors for mapping observations

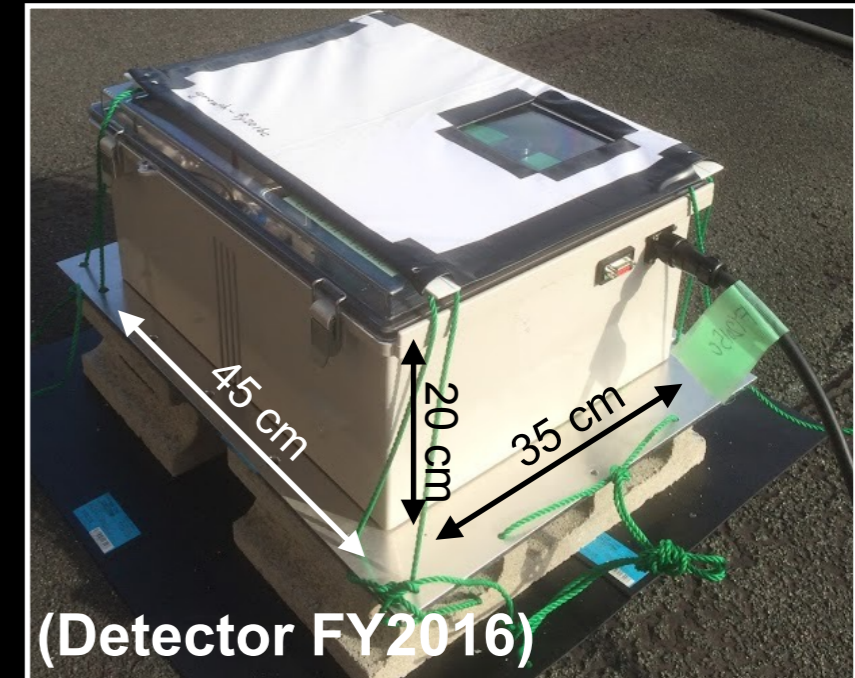
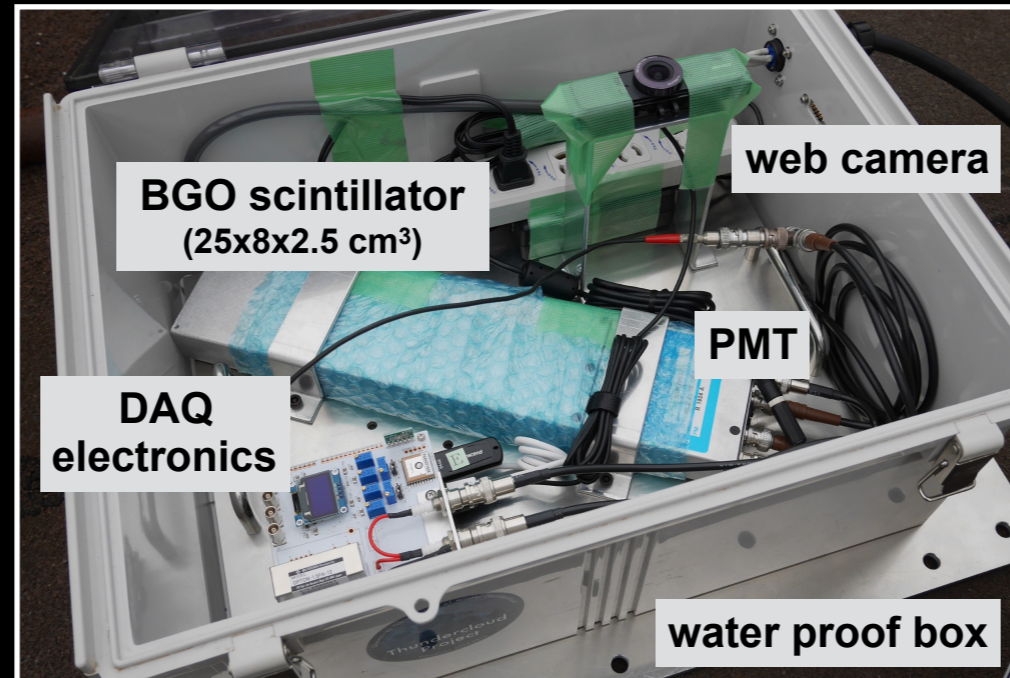
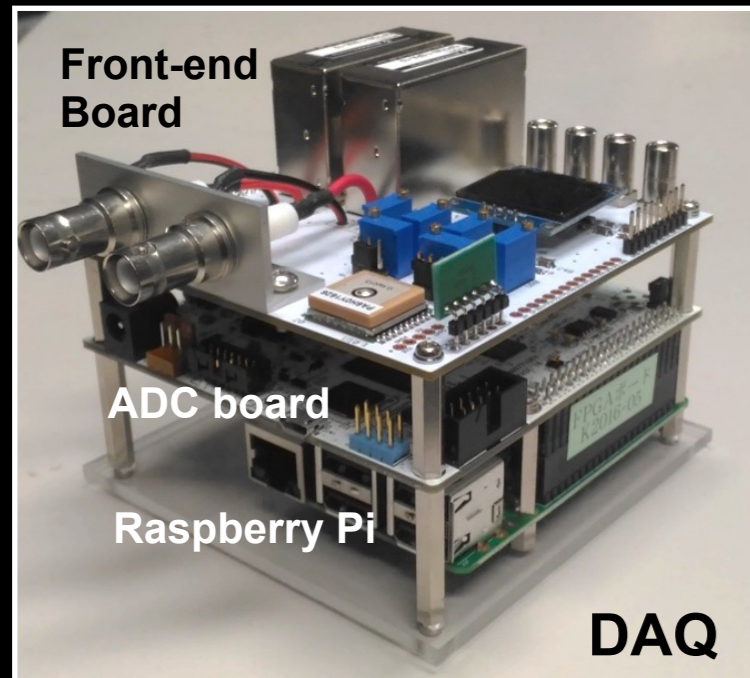
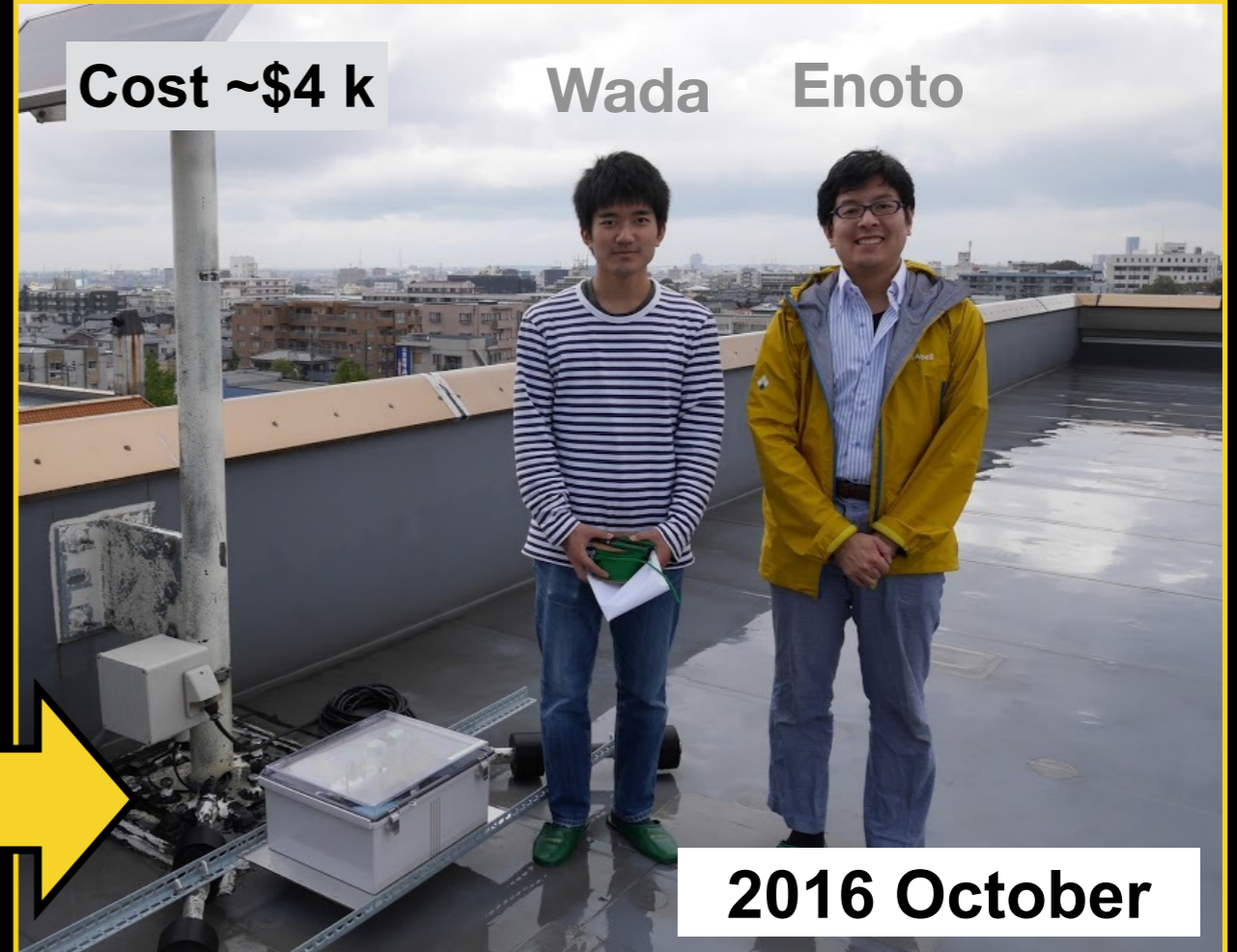
A new stand-alone, low cost, and high-performance data acquisition (DAQ) system was developed; e.g., FPGA board of 4 channel 50 MHz, 12 bit ADC



- Gamma-rays detected with BGO scintillators
- Recorded with energy and GPS time tag
- Waveform recording function is prepared
- Environmental sensors (temperature, pressure, etc)
- Mobile data transfer & remote control
- **Compatible with CubeSats, and aiming at distributing to citizen scientists**



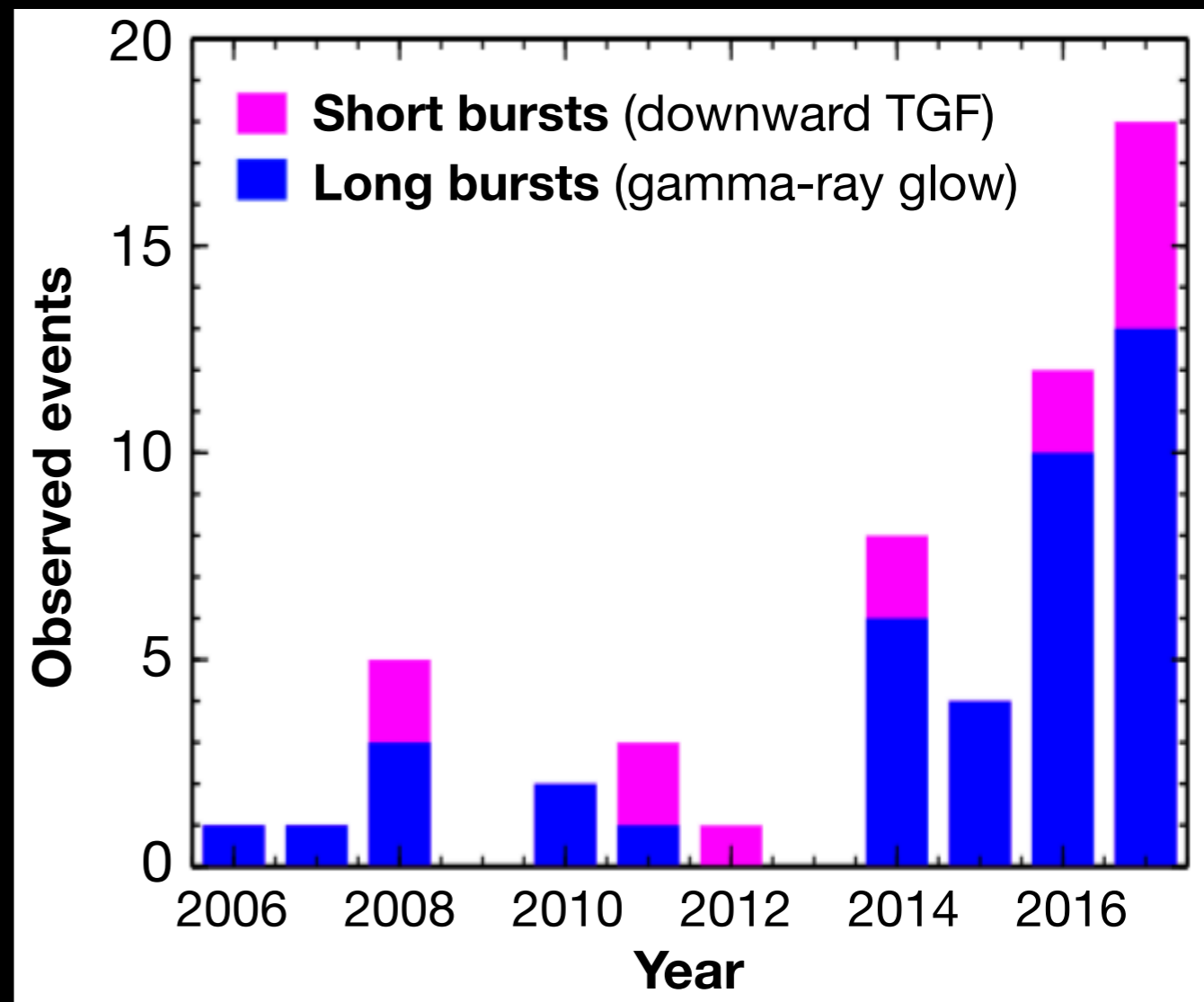
# Radiation detectors for mapping observations



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://ytiky.info/blog/2016/09/04/growth-fpga-adc-board/> (C) T. Yuasa

# GROWTH collaboration observation sites

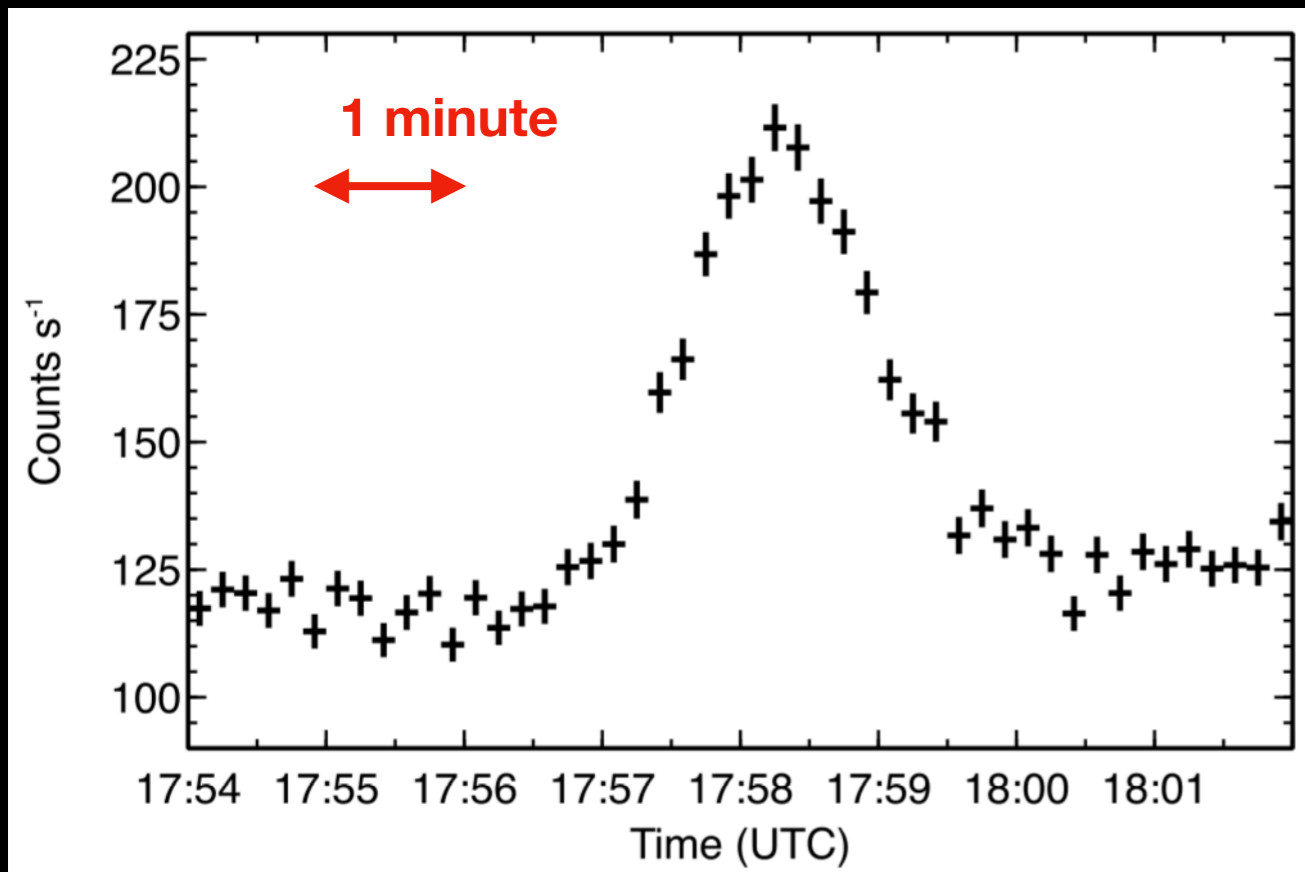
Multi-point observation of high-energy phenomena compared with moving thunderstorms and radio measurements of lightning discharge processes.



- 2006-2014: Only the Kashiwazaki site with 1-2 detectors
- 2015-: Starting mapping observation campaigns increased detections
- Developed at local high schools, universities, and private companies

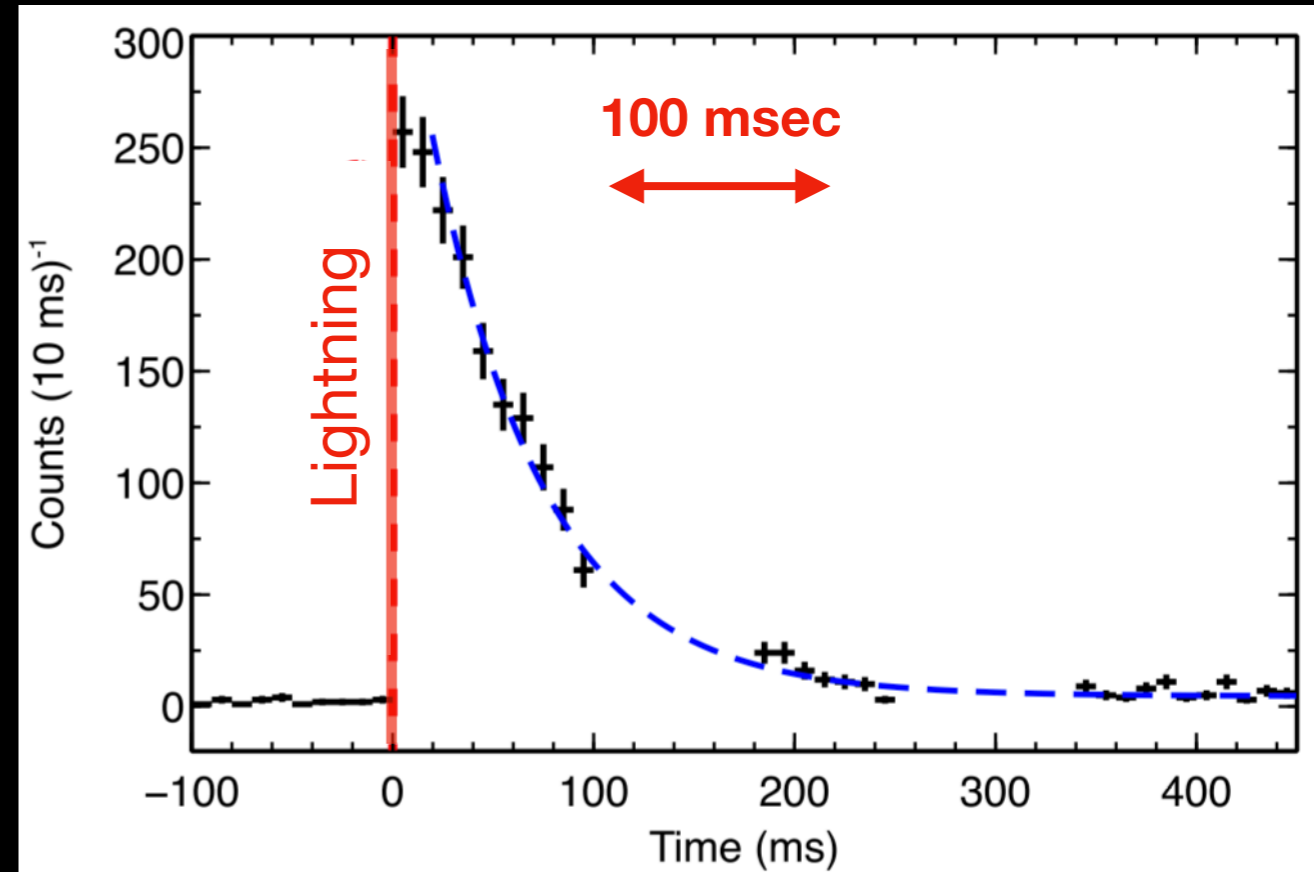
# Two types of high-energy radiation events

## Long burst gamma-ray glow



- Bremsstrahlung gamma rays from high-energy electrons accelerated by electric fields in thunderstorms
- 41 events since 2005 in total (13 events per year in 2017).

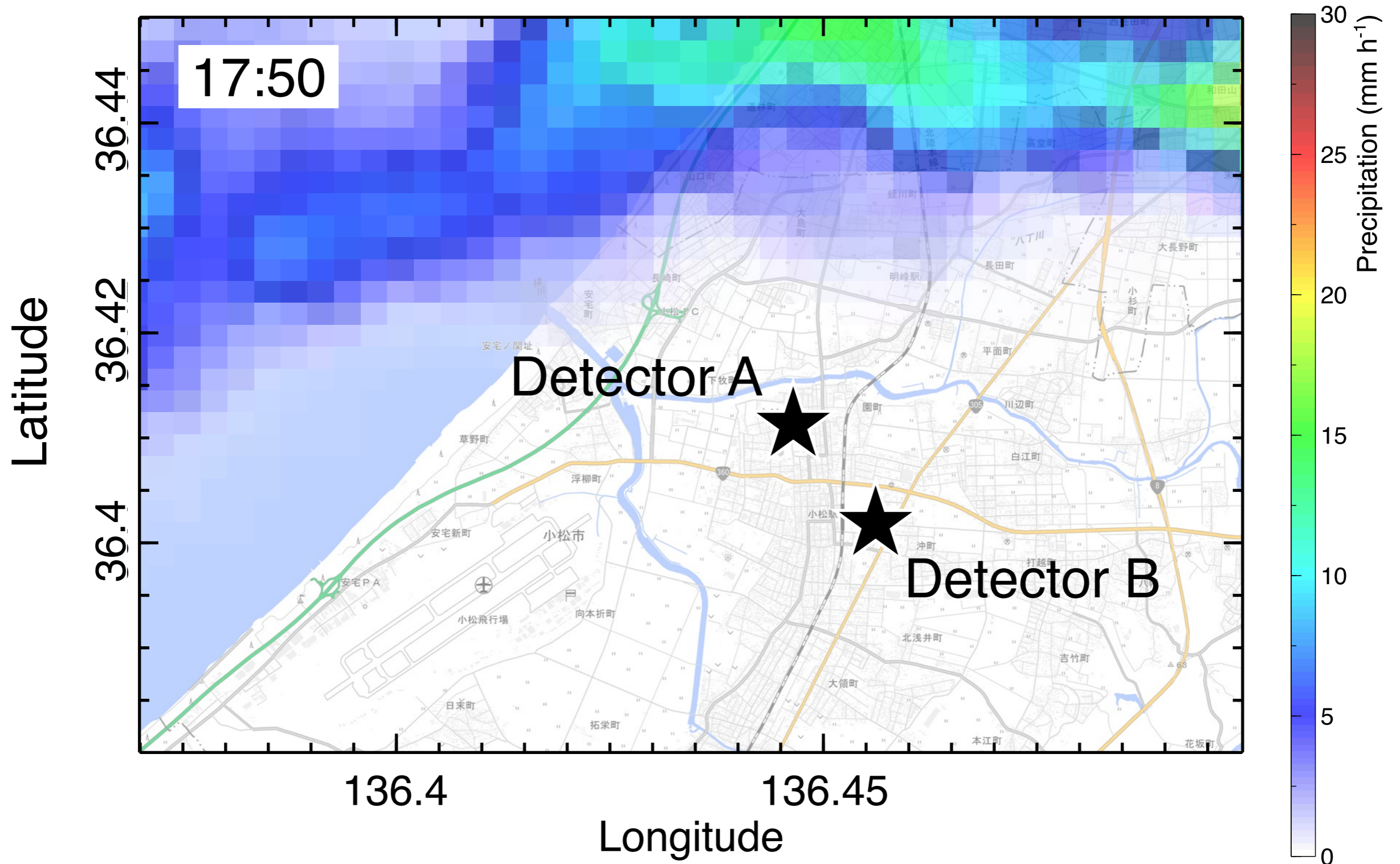
## Short burst photonuclear reaction



- Photonuclear reactions triggered by downwad terrestrial gamma-ray flashes associated lightning.
- 14 events since 2005 in total (5 events per year in 2017).

# Long burst (gamma-ray glow)

December 8, 2016, Komatsu city

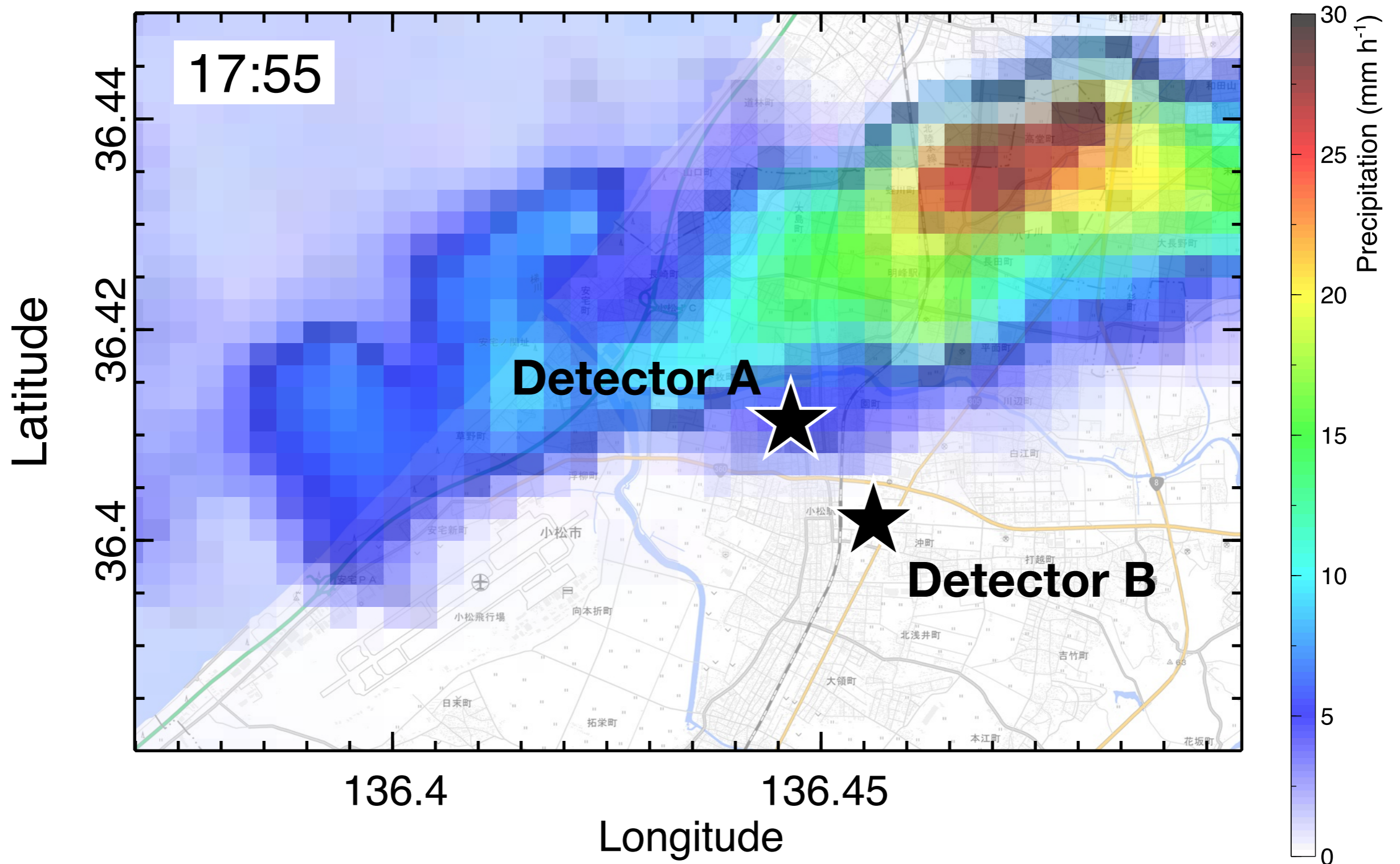


See details: Wada, TE et al. arXiv:1811.06212



# Long burst (gamma-ray glow)

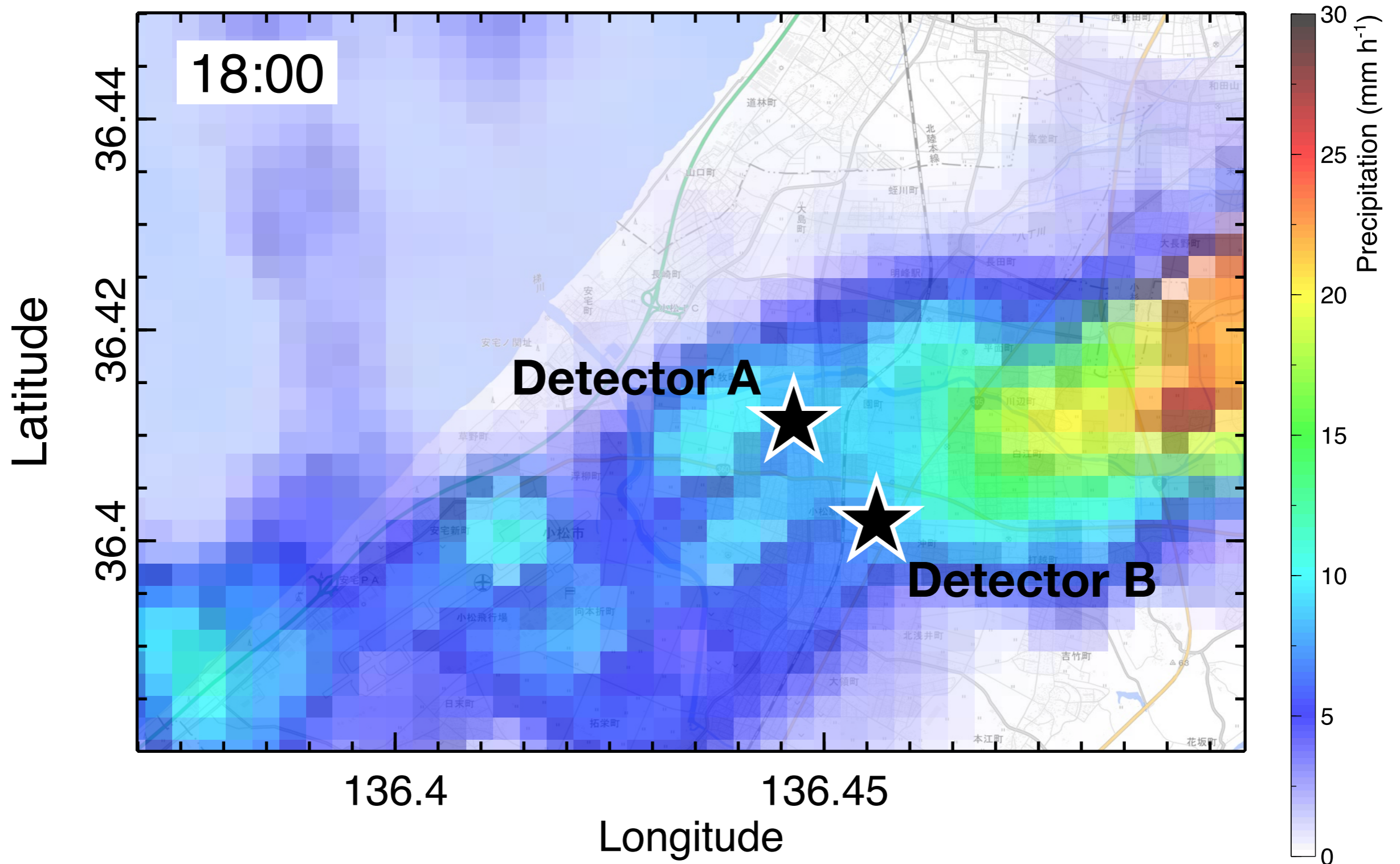
December 8, 2016, Komatsu city



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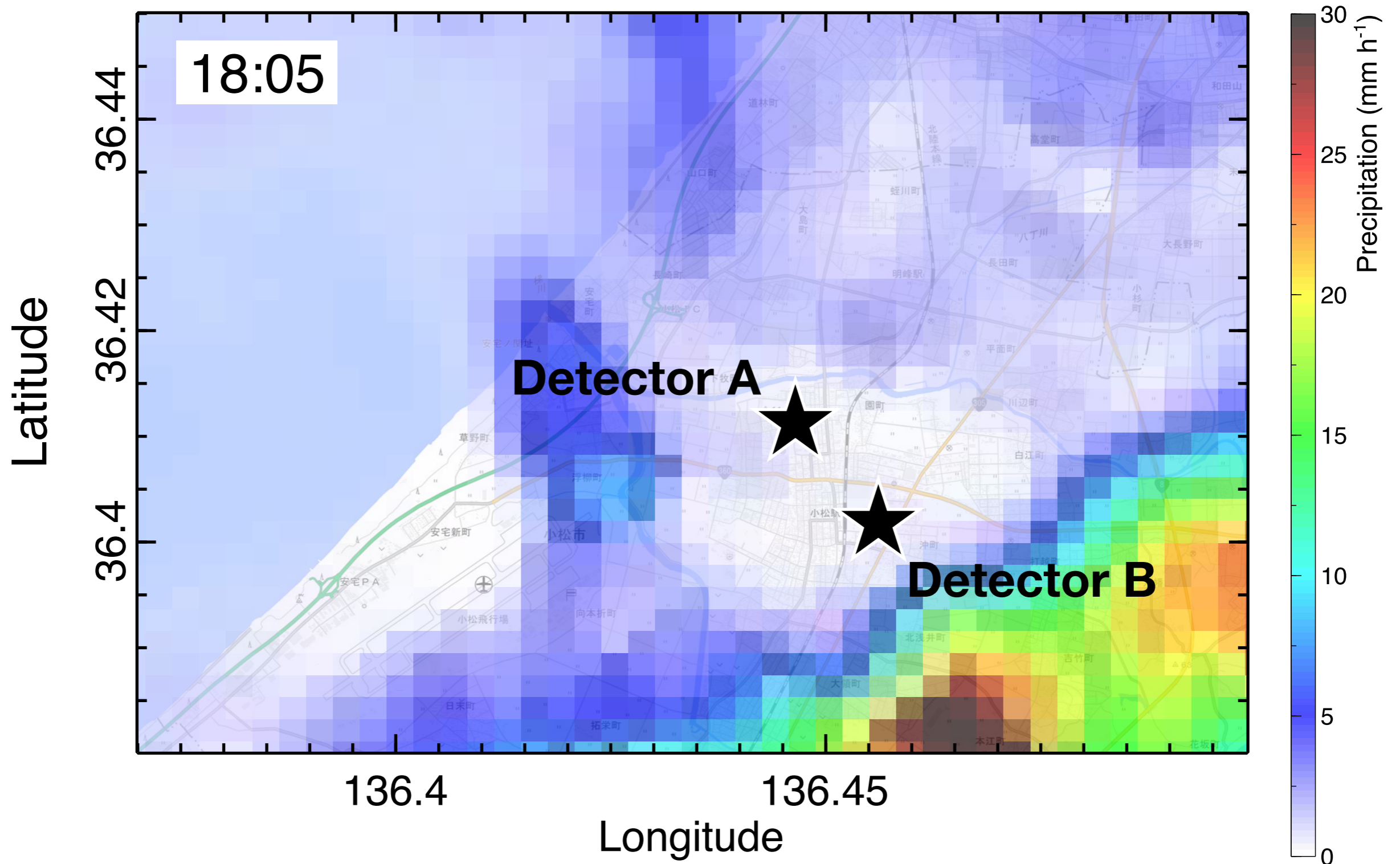
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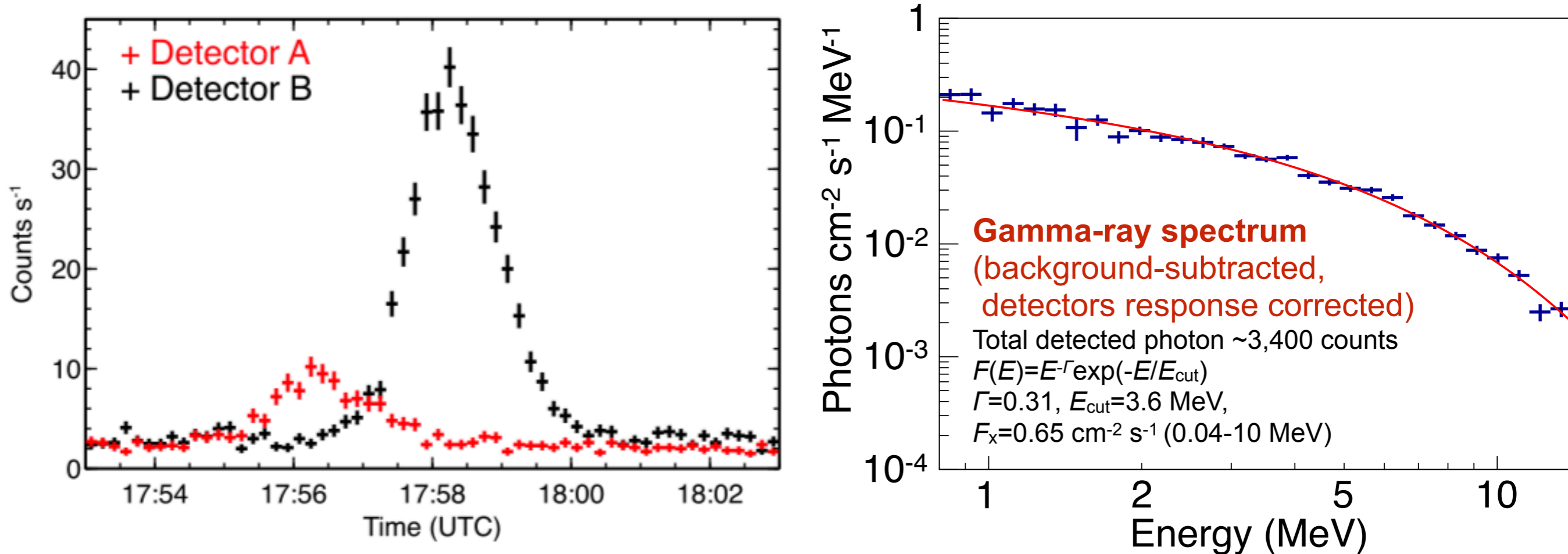
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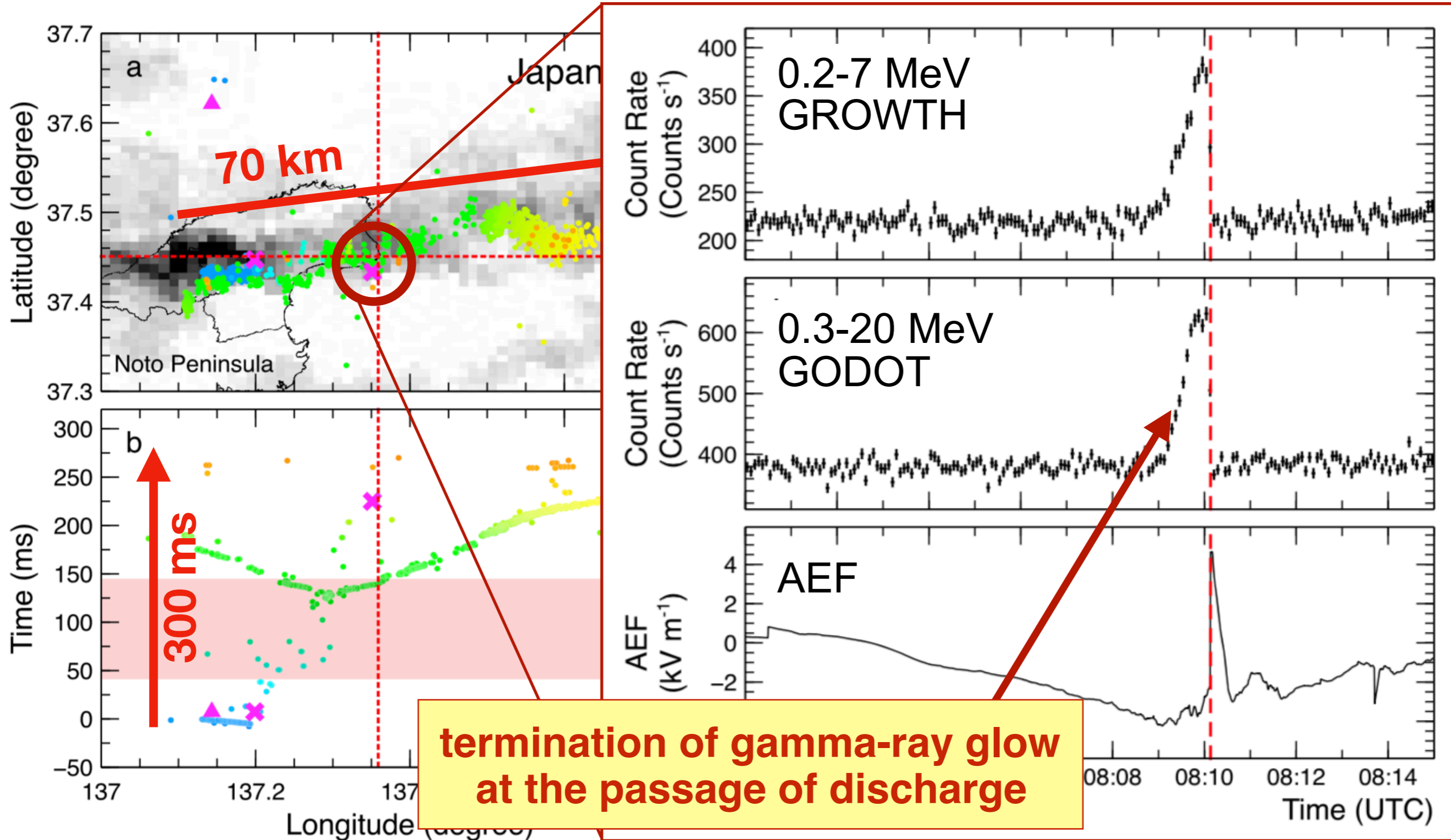
December 8, 2016, Komatsu city



- Prolonged gamma-ray detections as a dense cloud passed above two detectors. The delay is consistent with a speed of the moving cloud.
- Cutoff power-law gamma-ray spectrum extends above 20 MeV.
- Systematic analysis is now performed for all the gamma-ray glows compared with meteorological conditions (Matsumoto, Master thesis, 2019).

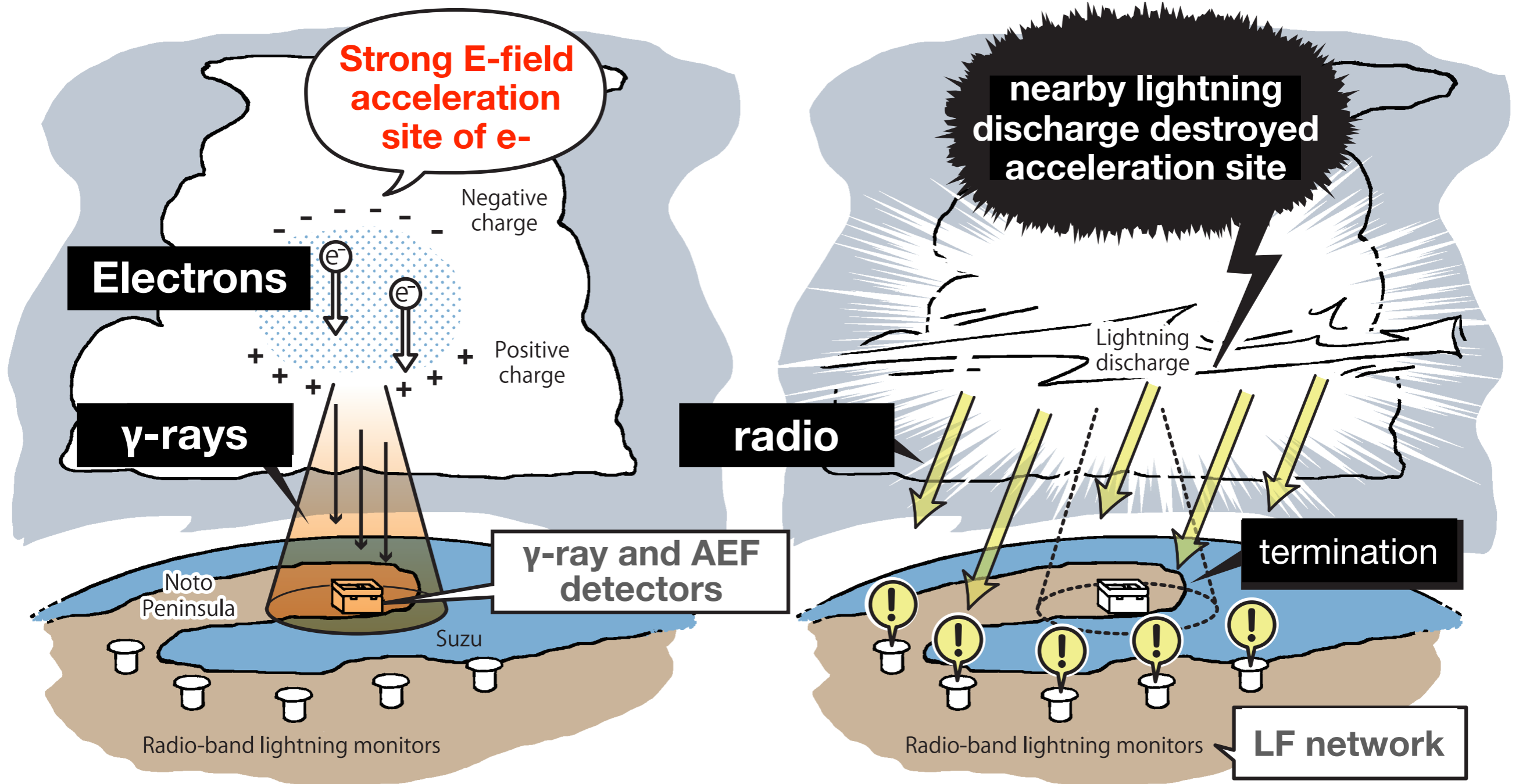
# Gamma-ray glow terminated with lightning

February 11, 2017, Suzu



# Gamma-ray glow terminated with lightning

February 11, 2017, Suzu



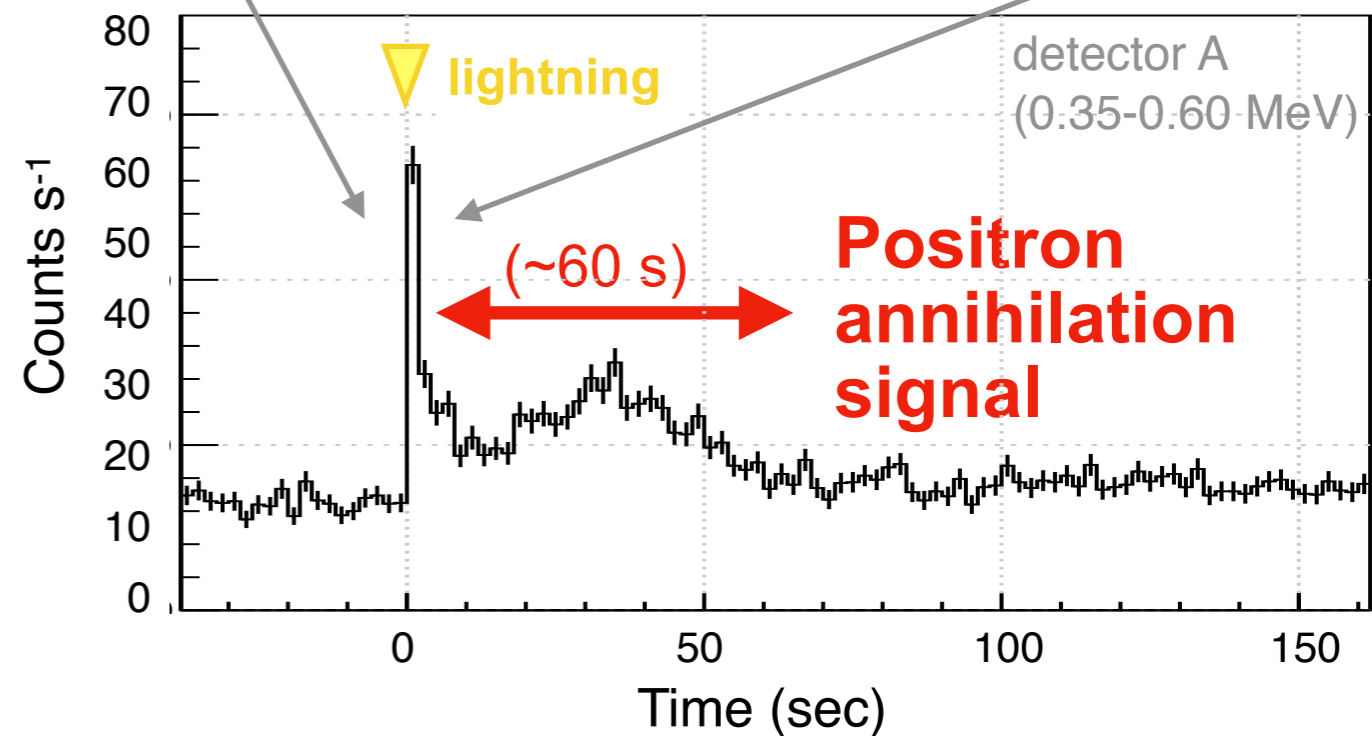
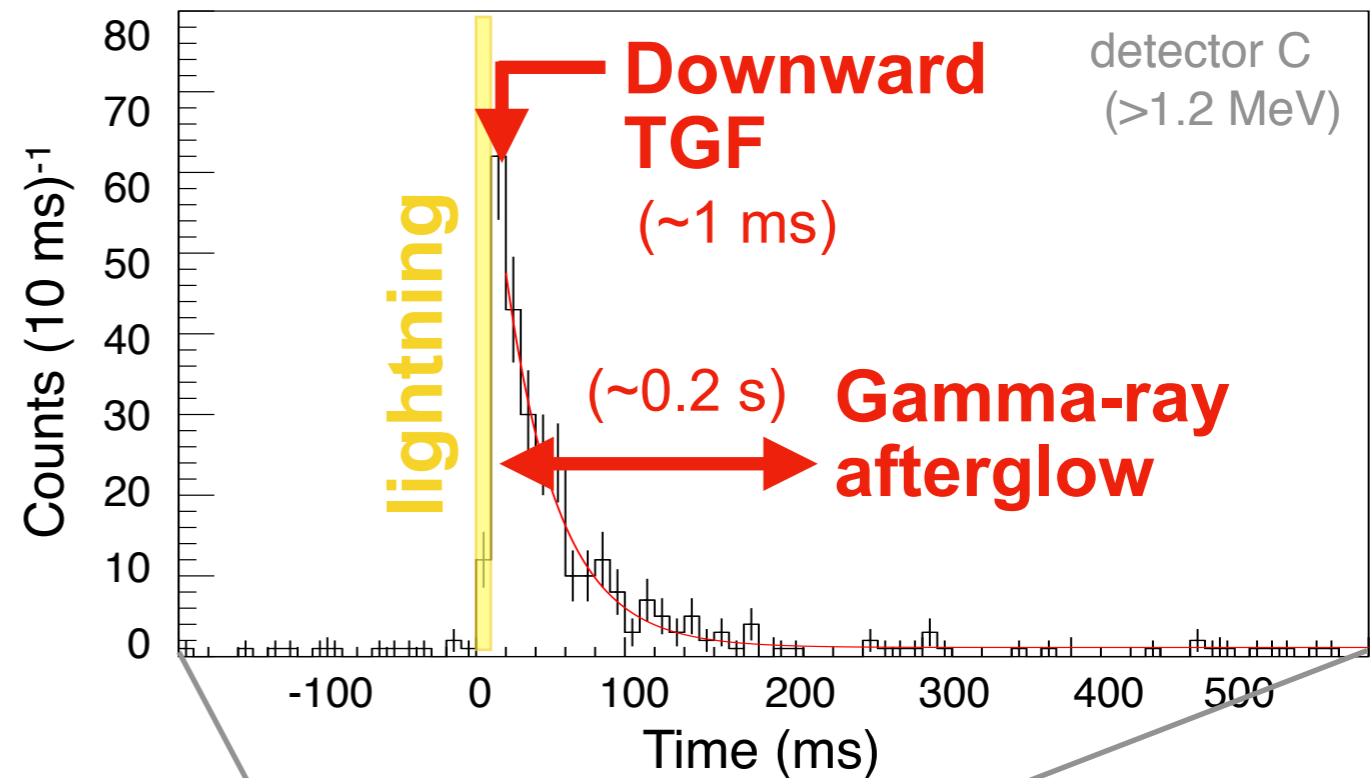
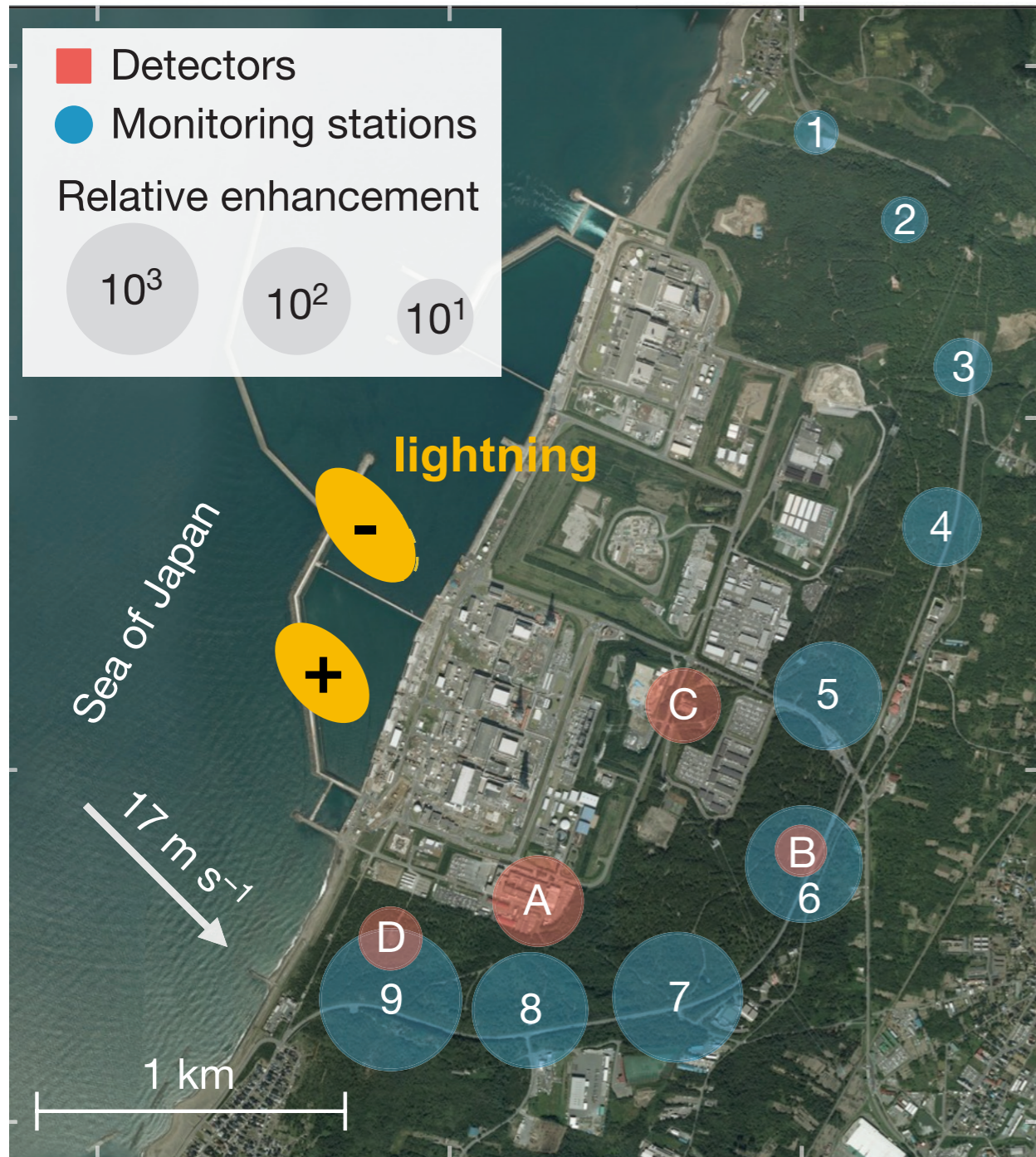
- Collaboration among gamma-ray radiation detections, atmospheric electric field measurement, and radio measurement of lightning

Wada, Bowers et al., *Geophys. Res. Lett.*, 48 (2018); See poster AE33A-3397

# Short bursts: Photonuclear reactions

February 6, 2017, Kashiwazaki

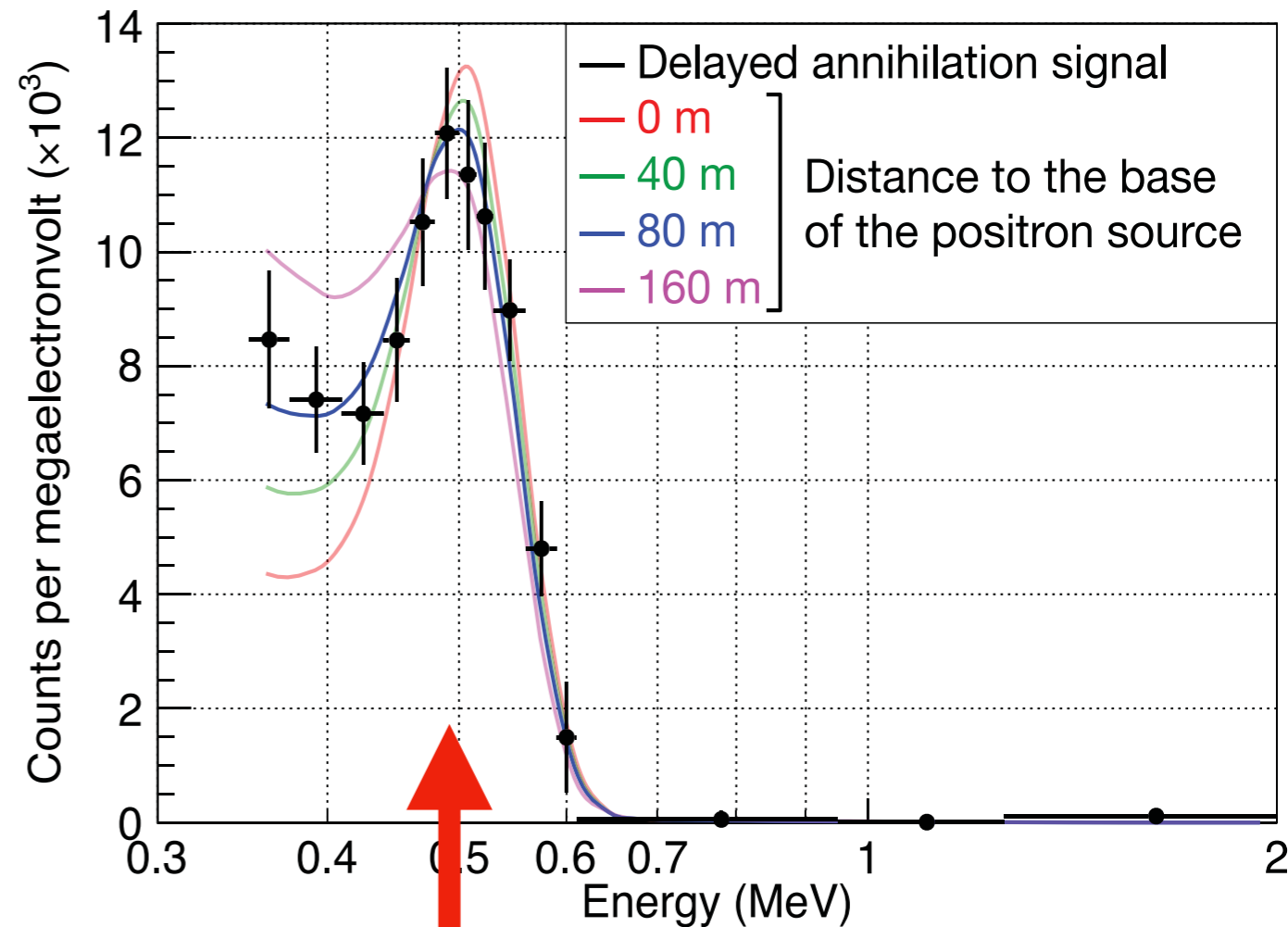
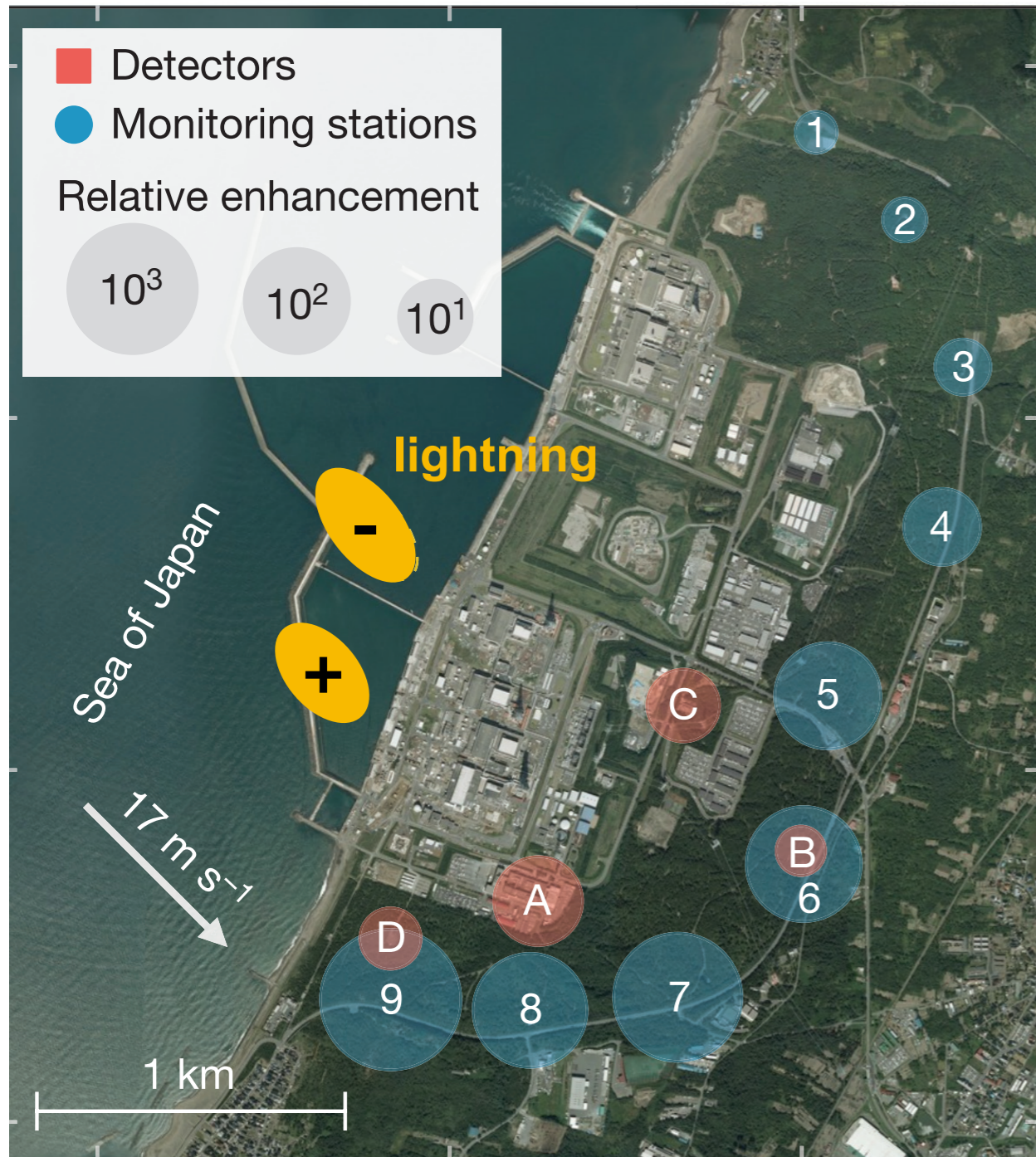
Three components: Lightning/TGF, Gamma-ray afterglow, and e<sup>+</sup>/e<sup>-</sup> line



# Short bursts: Photonuclear reactions

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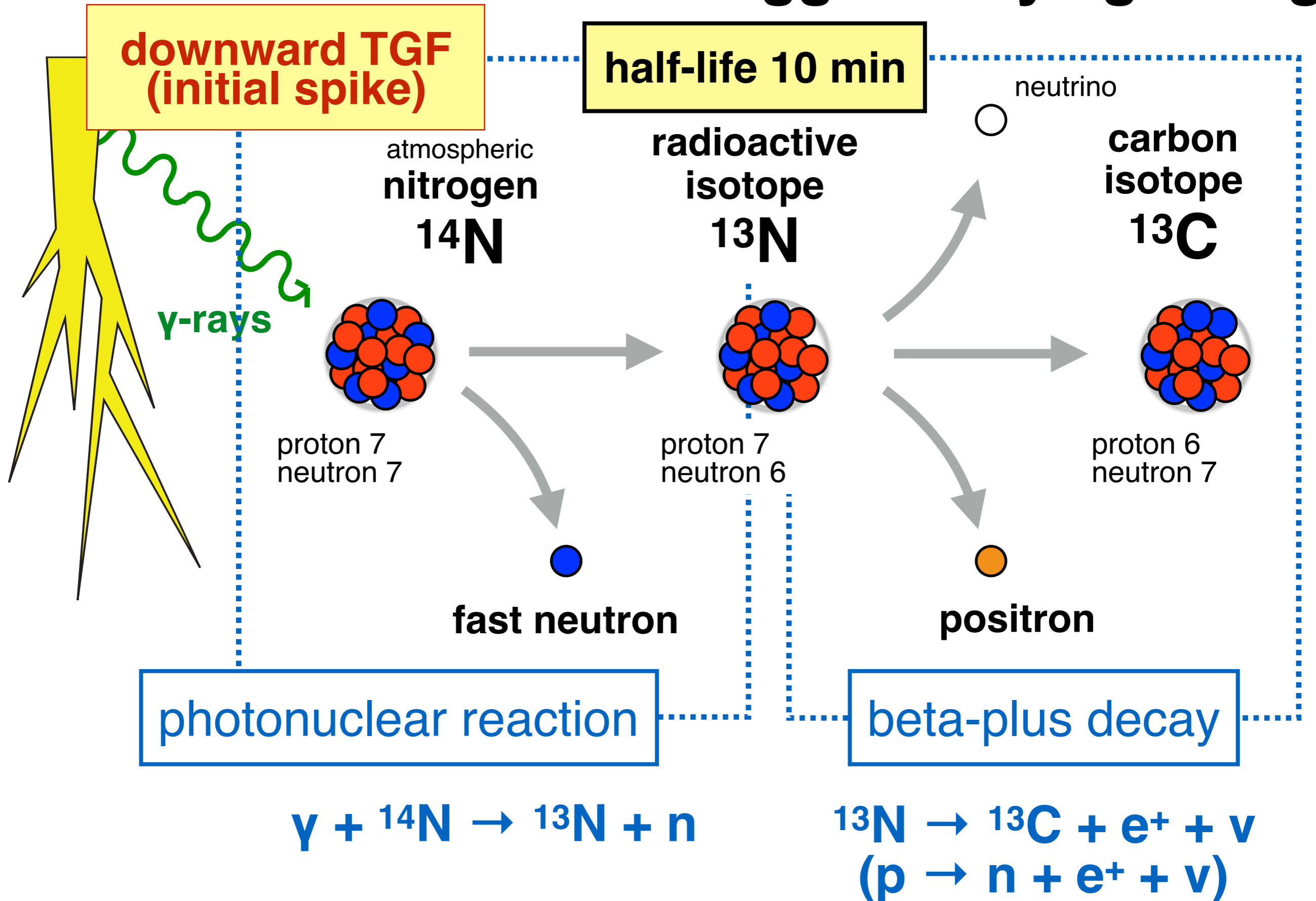
Three components: Lightning/TGF, Gamma-ray afterglow, and e<sup>+</sup>/e<sup>-</sup> line



**Detection of the positron annihilation line at 0.511 MeV**



# Photonuclear reactions triggered by lightning



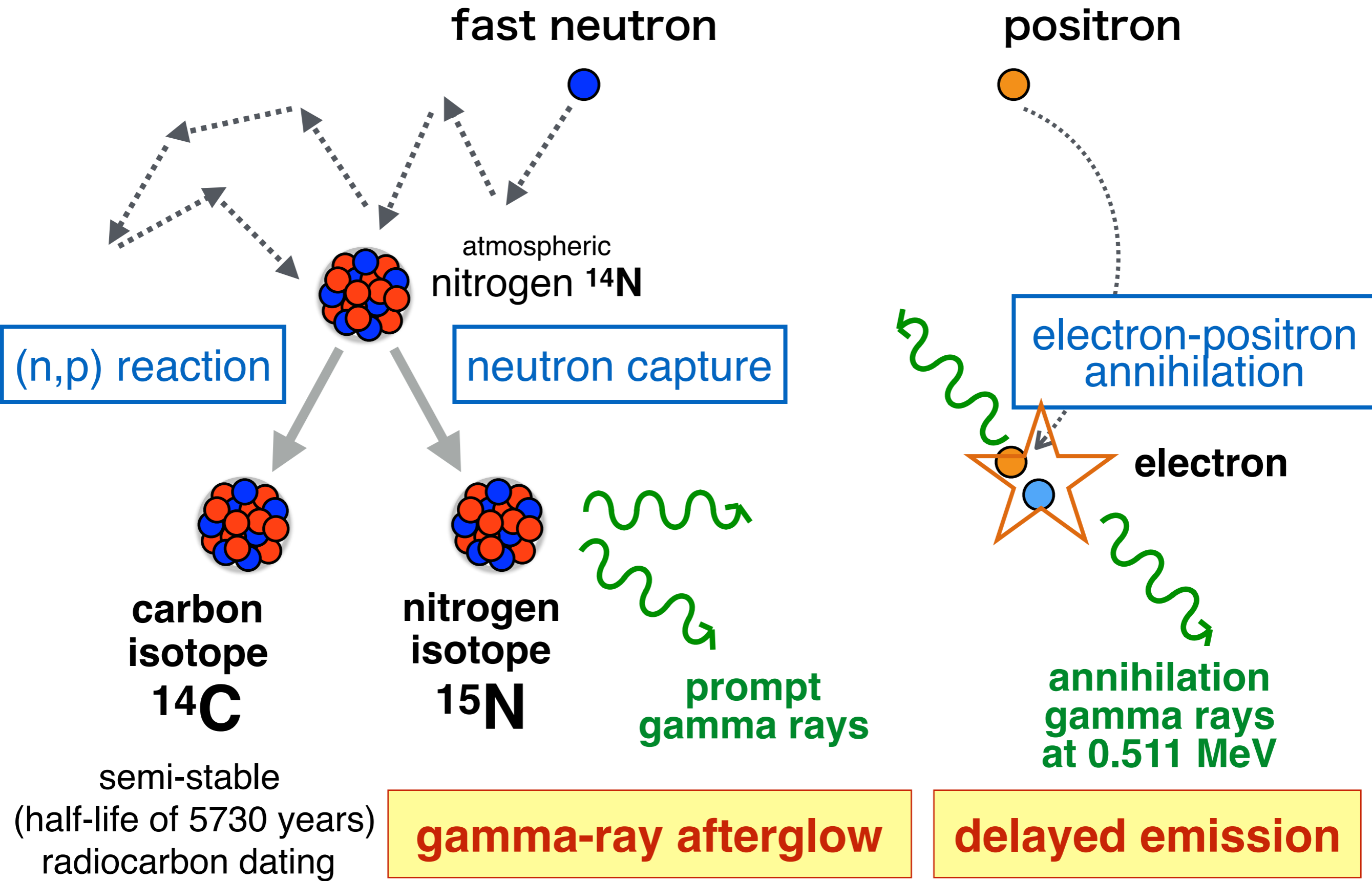
**fast neutron**



**positron**



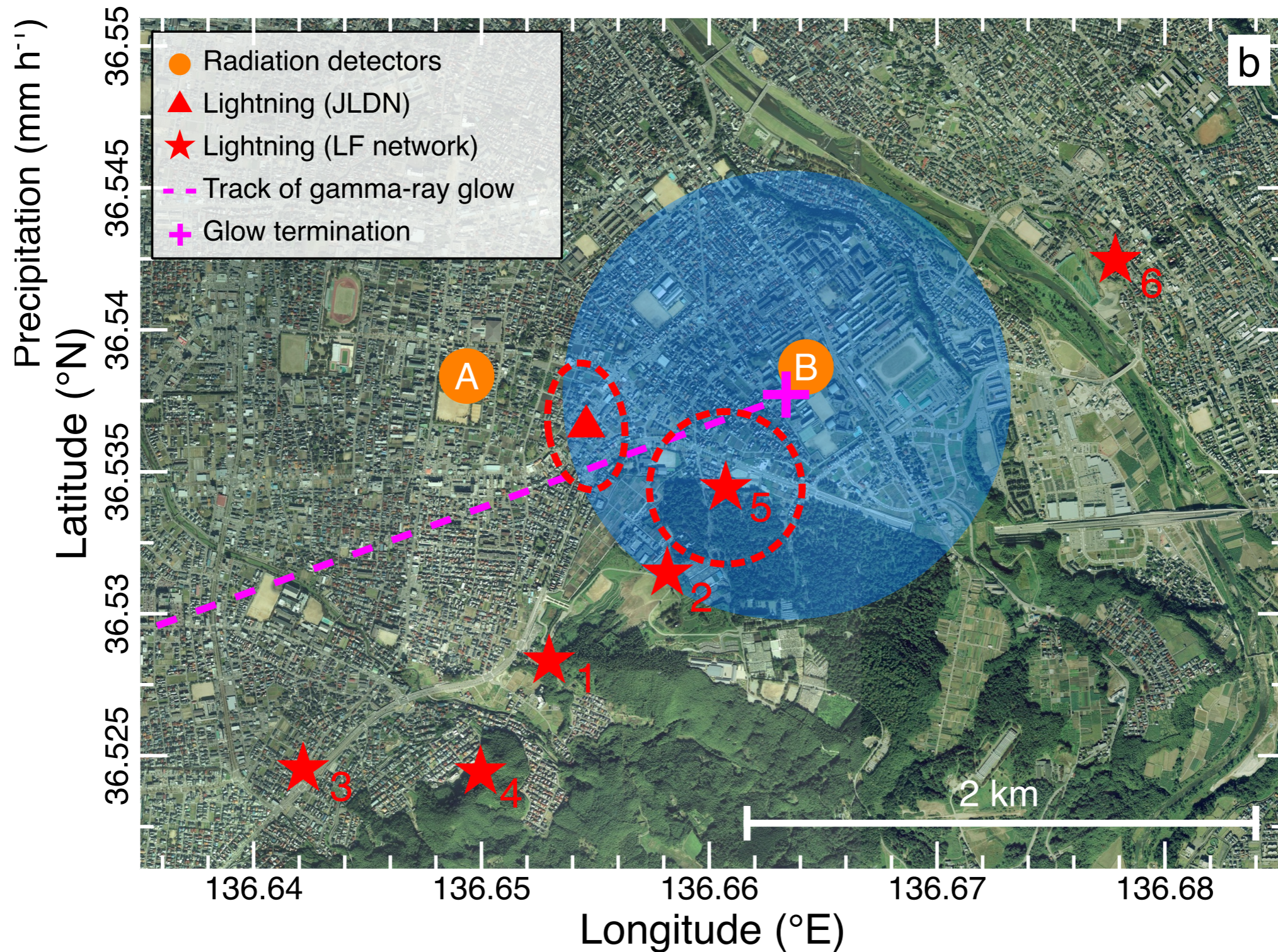
# Gamma rays from neutron and positrons



# New Event! Short burst just after long burst

January 9, 2018, Kanazawa

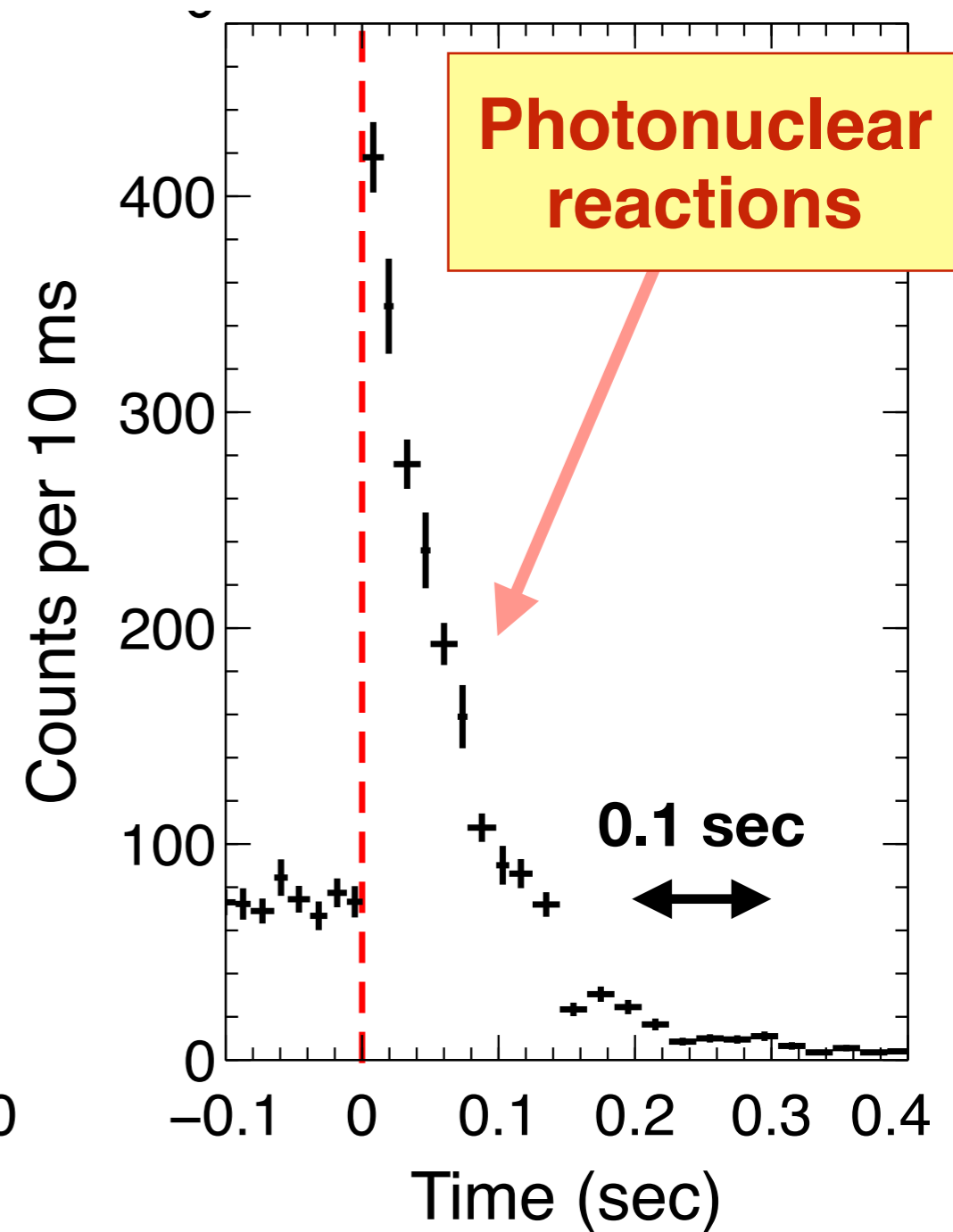
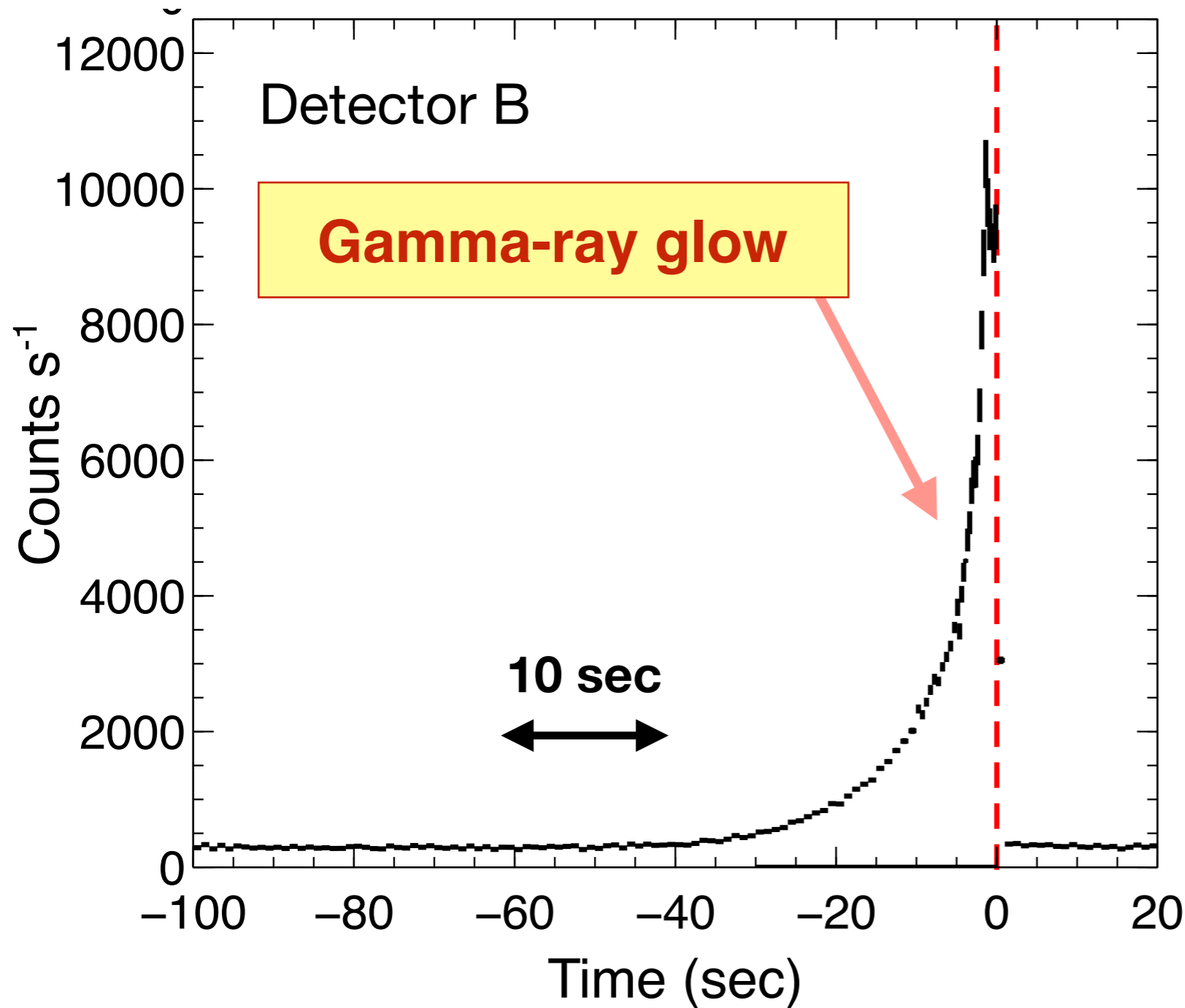
Gamma-ray glow terminated associated with photonuclear reactions



# New "long & short" associated Event

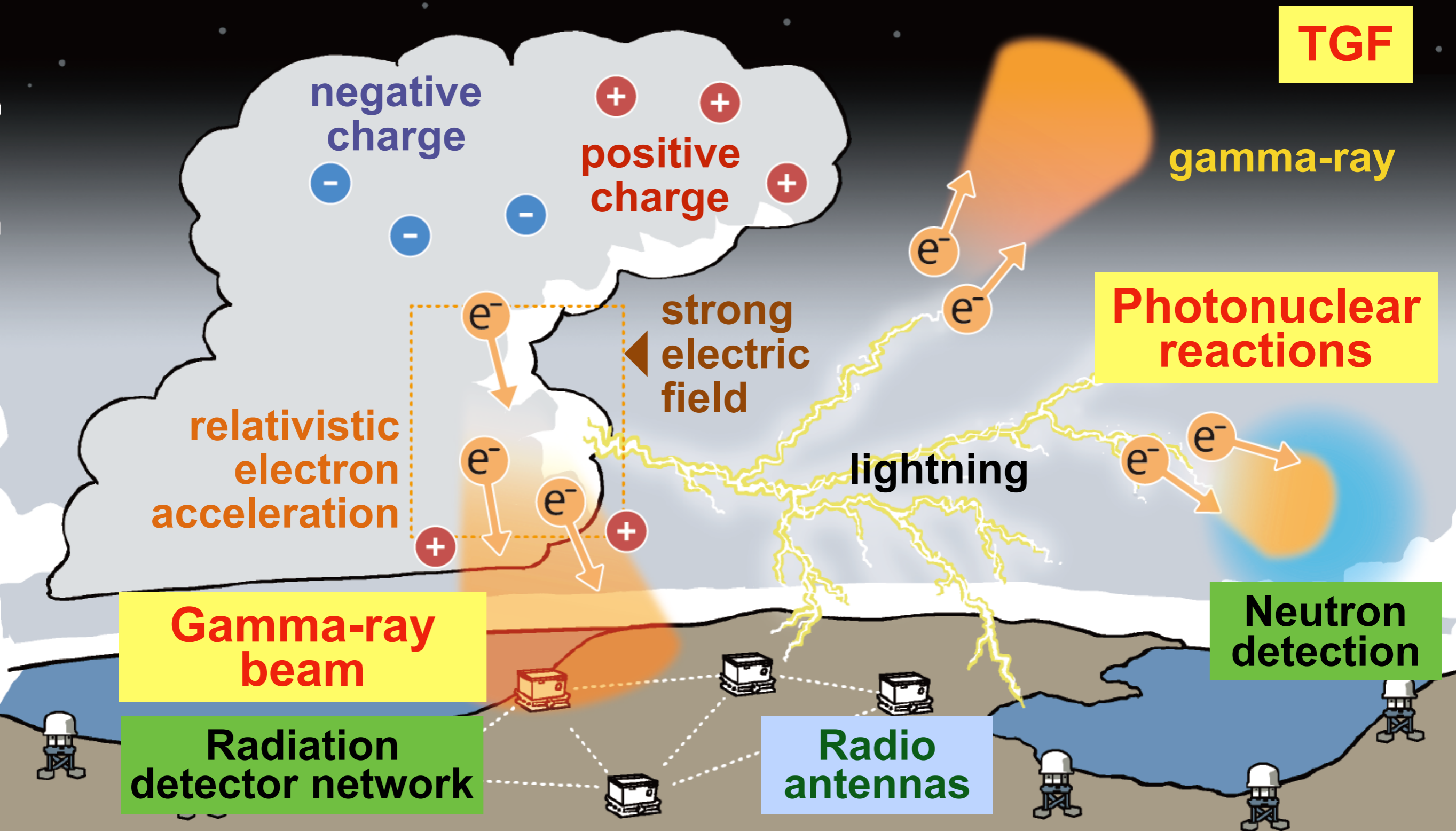
January 9, 2018, Kanazawa

Gamma-ray glow terminated associated with photonuclear reactions



# Kanazawa Comprehensive Observation

- On-ground gamma-ray multi-point observations simultaneous with atmospheric electric field and low-frequency radio measurements

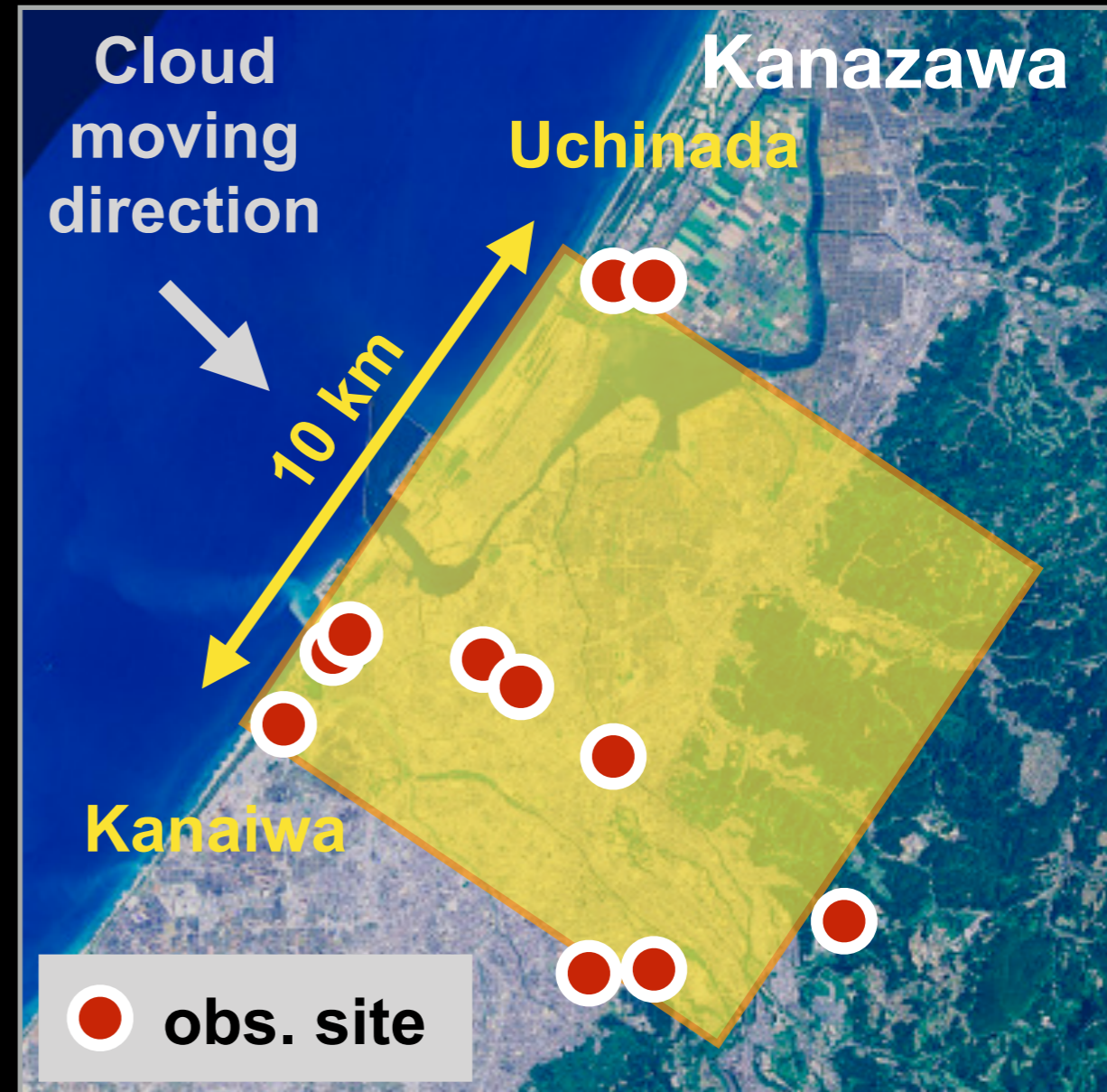


# Expanding the project to citizen science

- Main difficulty of the project is to ensure many observation sites
- A new handy radiation detector (reasonable price, easy to run!)
- A new organization “Kyoto Open Science Meetup” to support for communication among scientists and citizen supporters

2018 version

10 cm



# Summary

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



- **GROWTH collaboration started multipoint measurements of high-energy atmospheric phenomena along Japan Sea.**  
Tsuchiya, Enoto et al. PRL (2007)
- **The number of detection of long bursts (gamma-ray glow) is increasing (>41 events). We have started systematic study.**  
Matsumoto, Master thesis, in prep
- **Termination of the gamma-ray glow was recorded with a passage of a lightning discharge.** Wada, Bowers et al., GRL (2018)
- **Photonuclear reactions by downward terrestrial gamma-ray flashes have been detected as short bursts (14 events).**  
Enoto, Wada, et al. Nature (2017)
- **We have expanding our project to citizen science at Kanazawa area. We detected the “short & long” burst event in this area.**