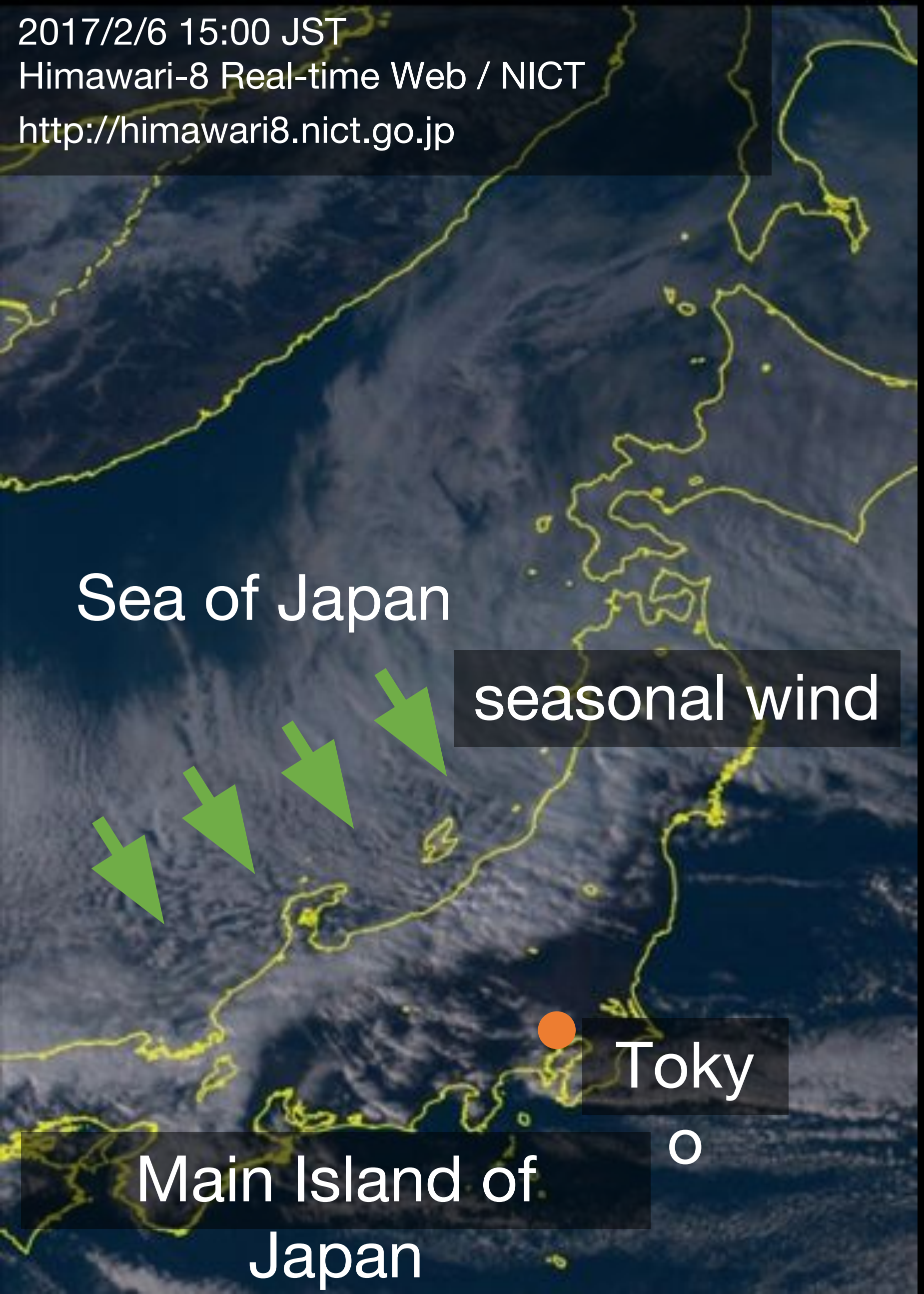
Recent Updates from Mapping Observation of High-Energy Phenomena In Japanese Winter Thunderstorms

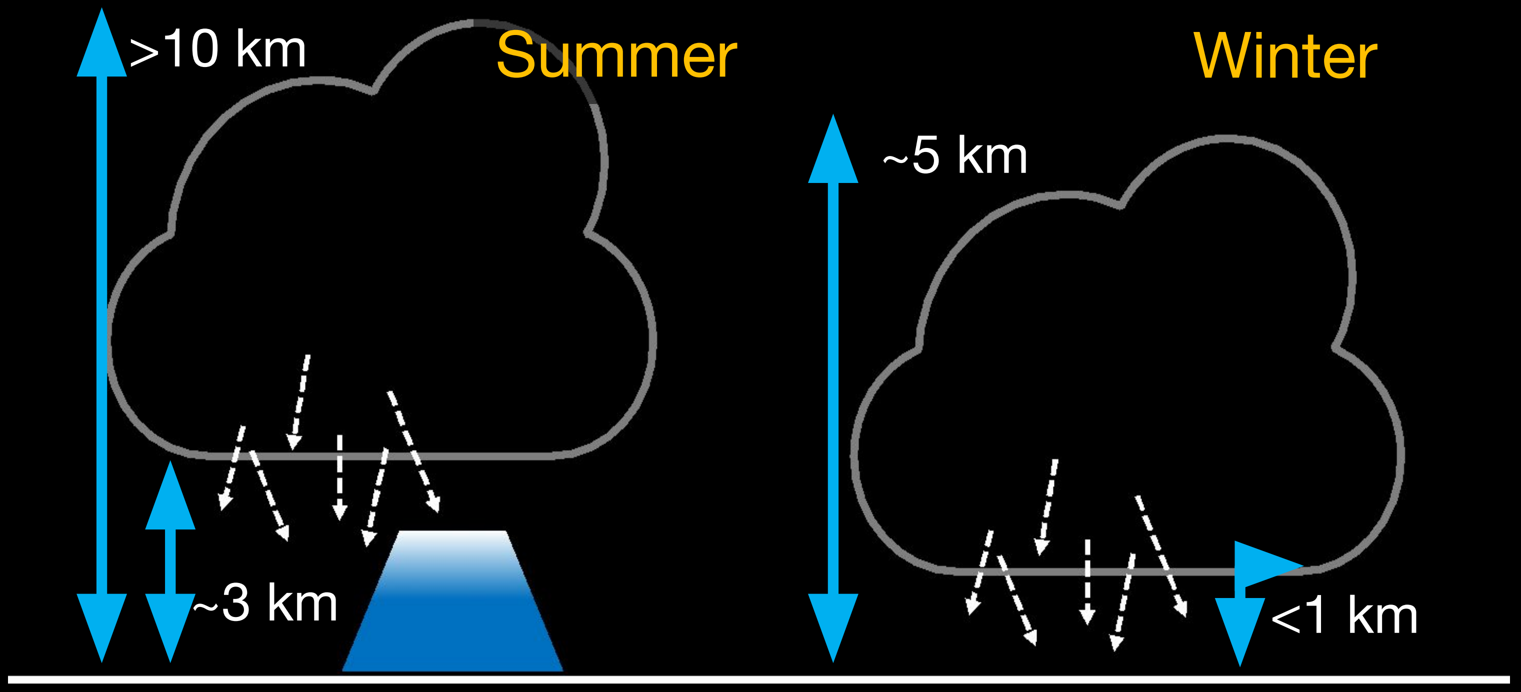
Yuuki Wada (The University of Tokyo / RIKEN)
Teruaki Enoto, Yoshihiro Furuta, Kazuhiro Nakazawa, Takayuki Yuasa, Takahiro Matsumoto,
Daigo Umemoto, Kazuo Makishima, Harufumi Tsuchiya, and the GROWTH collaboration

TEPA2018@Yerevan Physics Institute, Armenia (2018/09/18 10:00-10:30)

High-energy Phenomena in Japanese Winter Thunderstorms

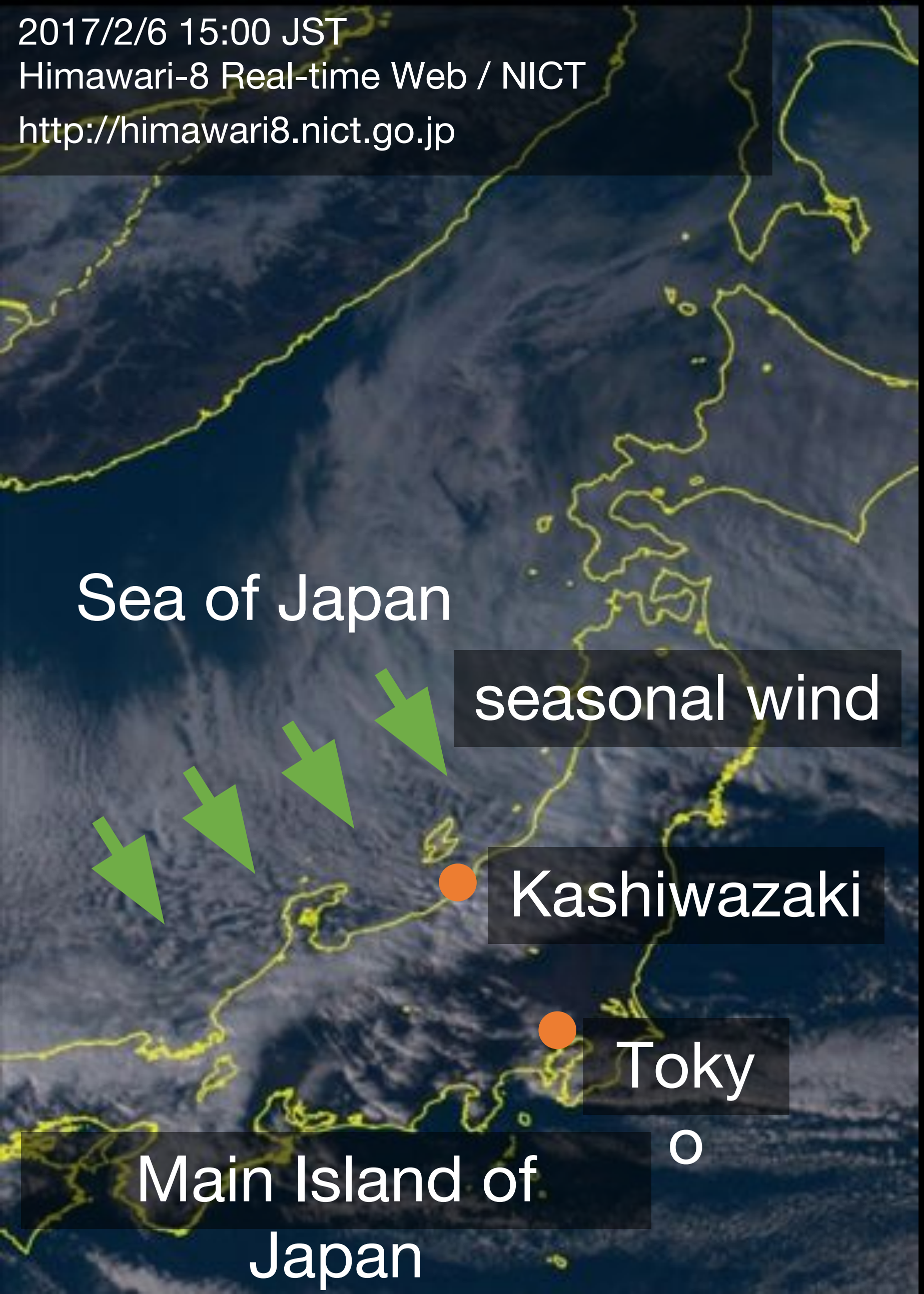


- Winter thunderstorms along Sea of Japan
  - Powerful and frequent lightning
  - Large and positive current discharges
  - Lower cloud base (< 1 km: Goto & Narita 1992)

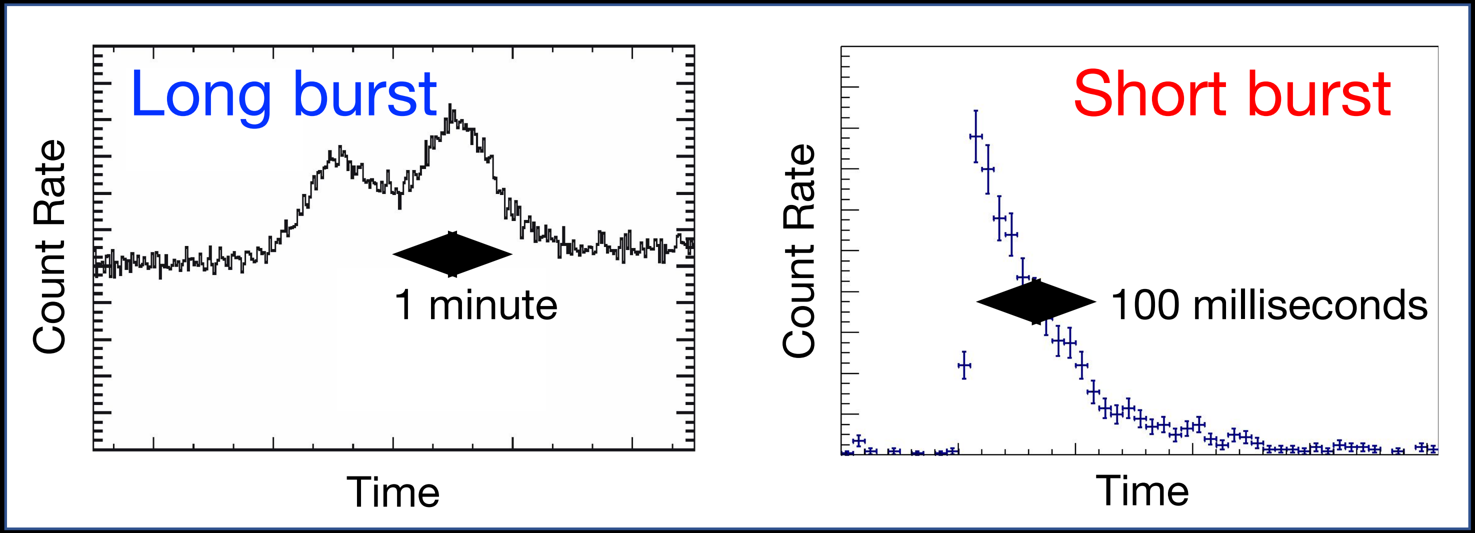


- High-energy phenomena have been observed by
  - Monitoring stations of nuclear plants (Torii+02)
  - Sea-level experiments (e.g. Tsuchiya+07, Kuroda+16)

Gamma-Ray Observation of Winter Thundercloud

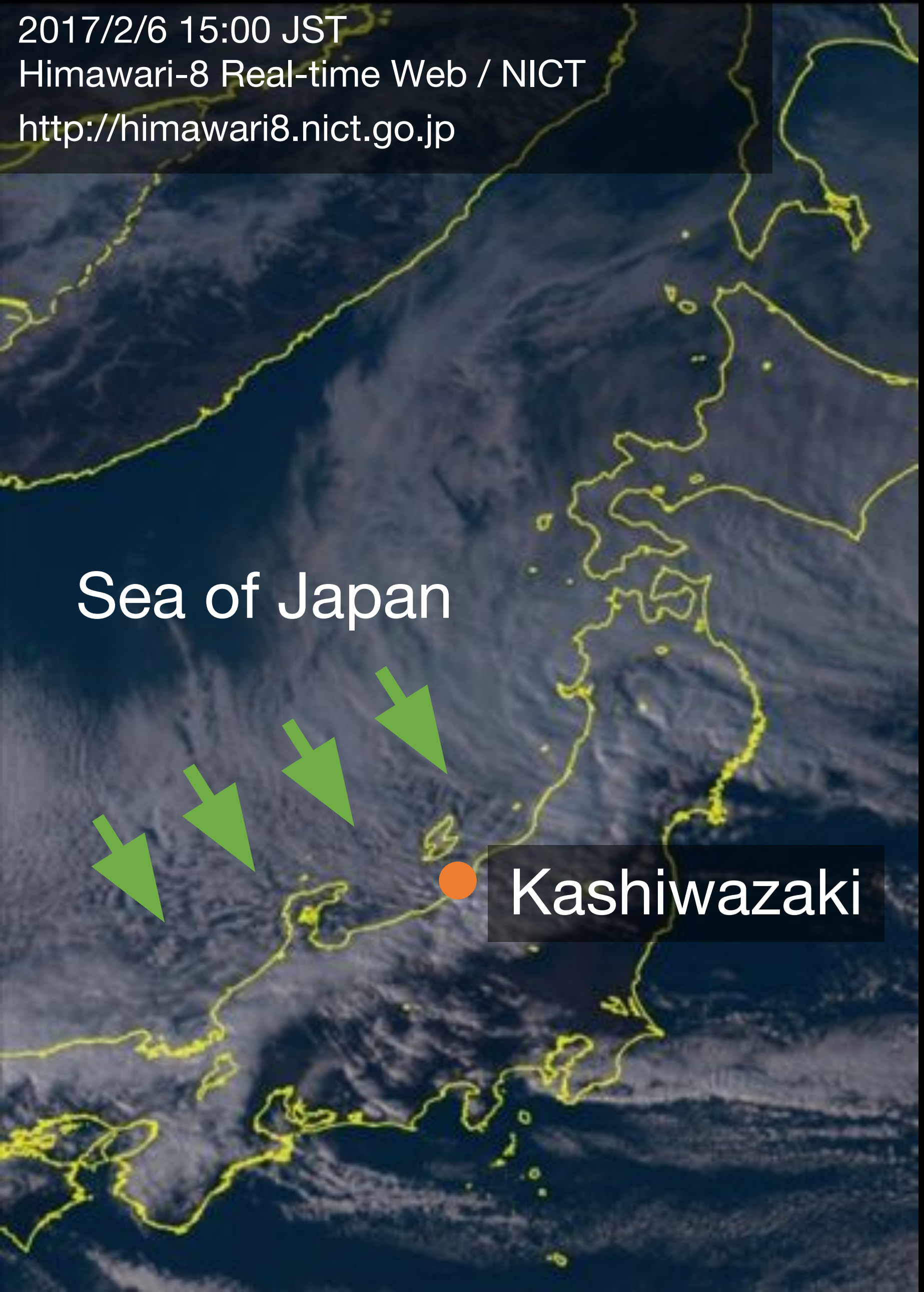


- The GROWTH experiment started in 2006 at Kashiwazaki-Kariwa Nuclear Power Plant.
- We have observed long bursts from thunderclouds (as known as TGEs and gamma-ray glows) and short bursts from lightning discharges.



- 28 events in 10 years (2006-2015) at Kashiwazaki
(Tsuchiya et al. 2007, 2011, 2013, Umemoto et al. 2016)

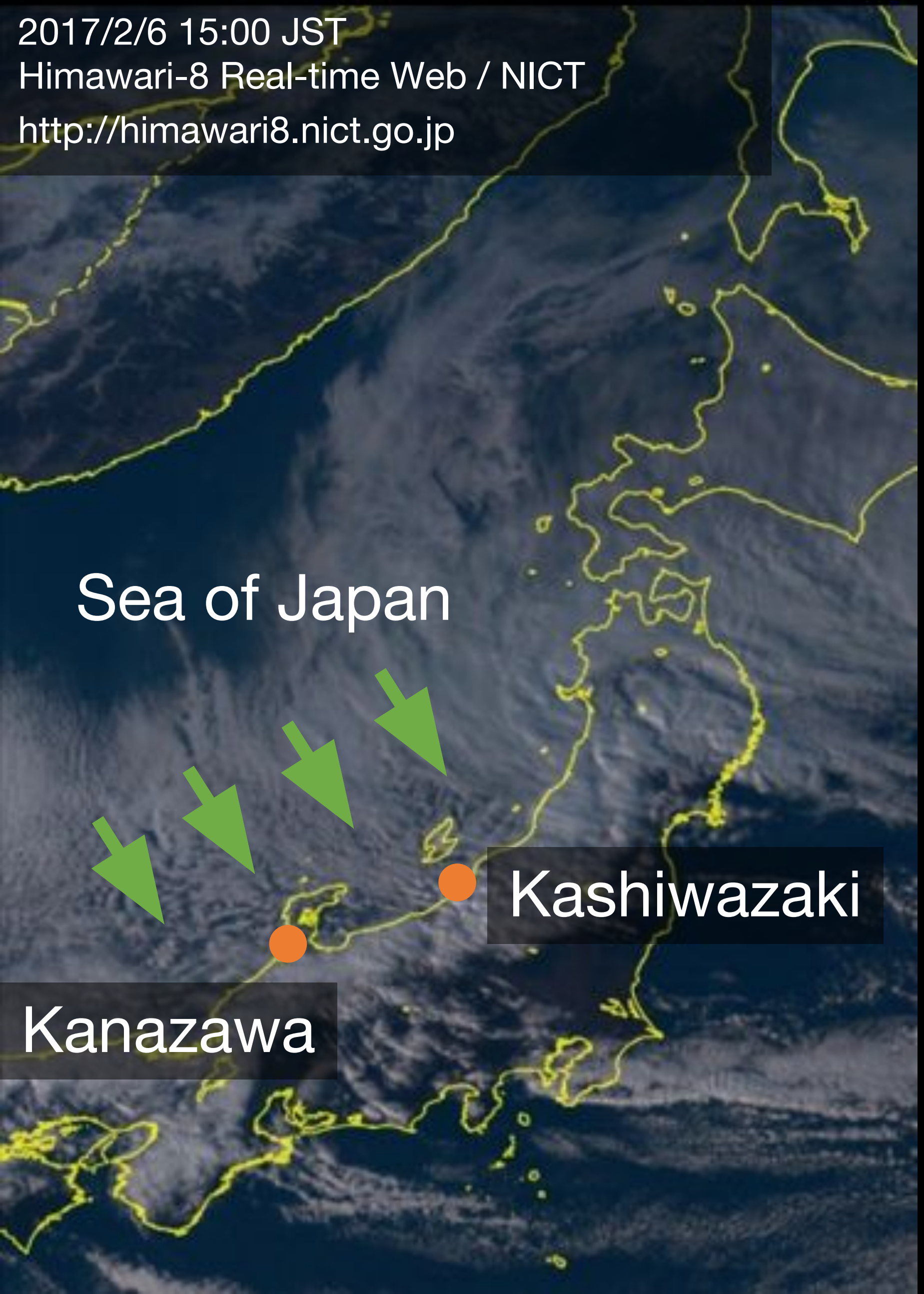
Mapping Observation Campaigns



- Two detectors in Kashiwazaki until 2015.
- How to answer remaining questions?
  - Life cycle of long bursts
  - Structure of acceleration region
  - Total fluxes of long & short bursts

-> **Mapping observation with portable detectors**

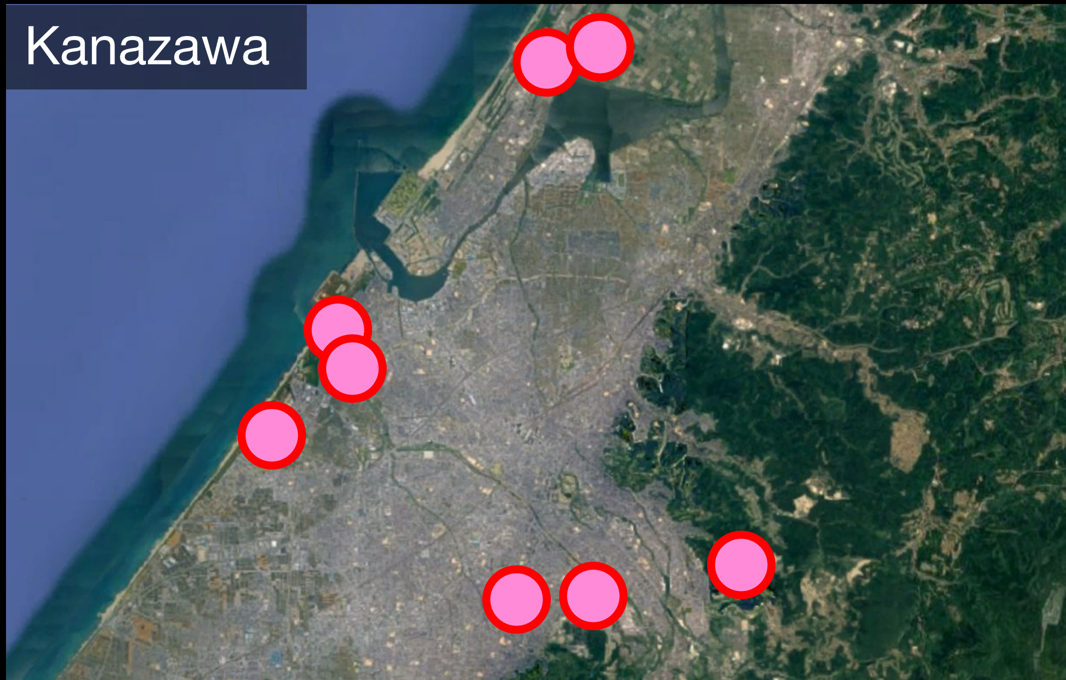
Mapping Observation Campaigns



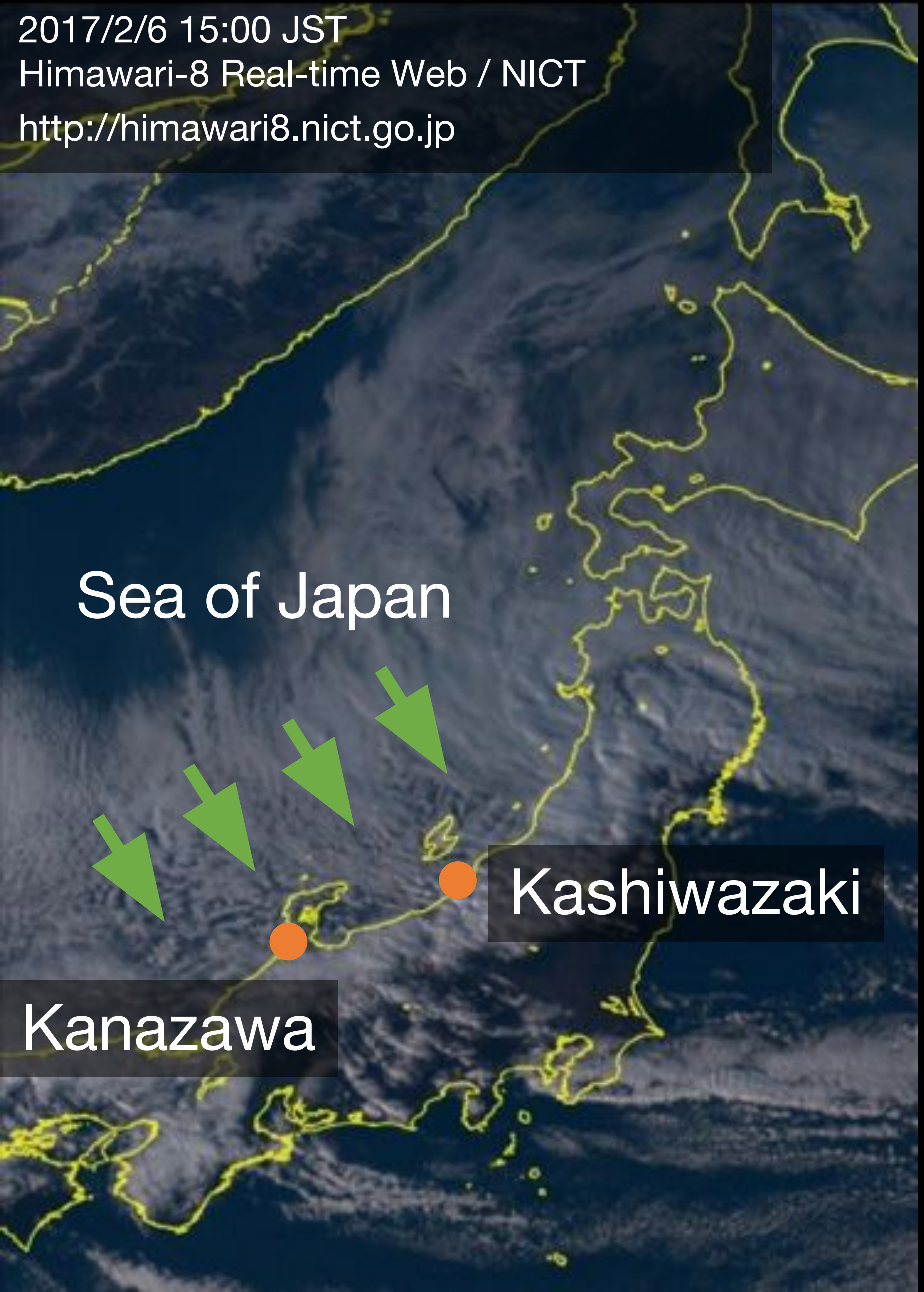
- Kanazawa observation site since 2015
  - Frequent lightning during winter seasons
  - Wide plain and urban area

  -> **Suitable for long burst hunting**

  -> **Easy to find installation sites**
  - 8 detectors in 2017-2018 winter season



Mapping Observation Campaigns



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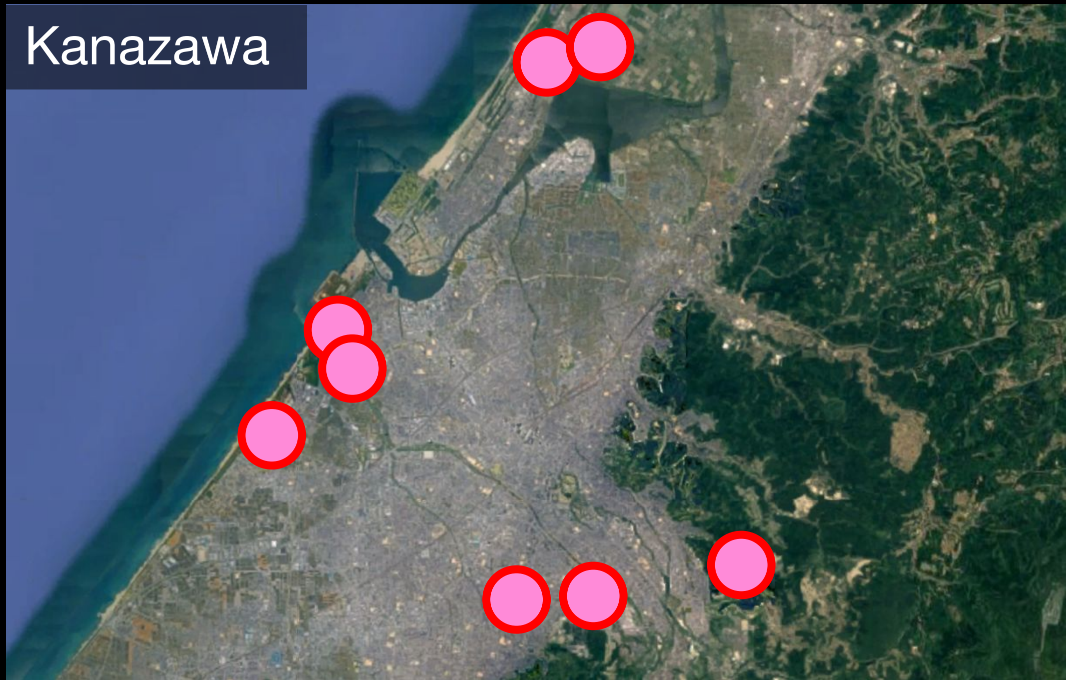
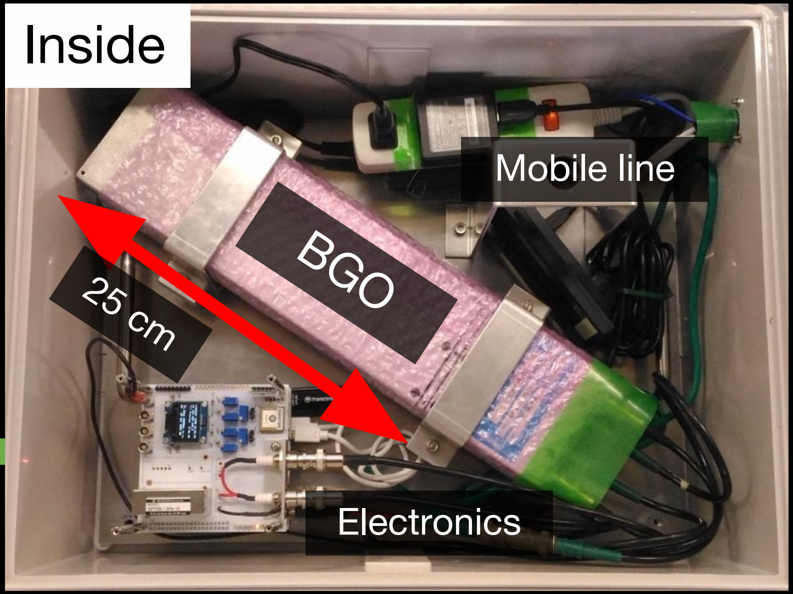
  - 8 detectors in 2017-2018 winter season
- **Updated Kashiwazaki site with 4 detectors**



Development of Portable Radiation Detectors

Simple configuration

- BGO or CsI crystals for gamma-ray detection
- Compact data acquisition (DAQ) system
- Mobile data connection for monitoring and data transfer
- Powered by external electricity (AC100V in Japan)

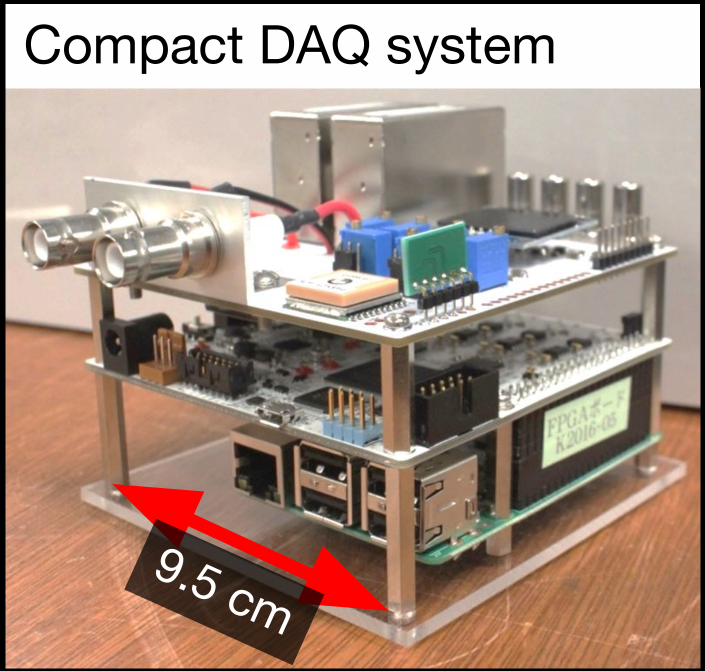


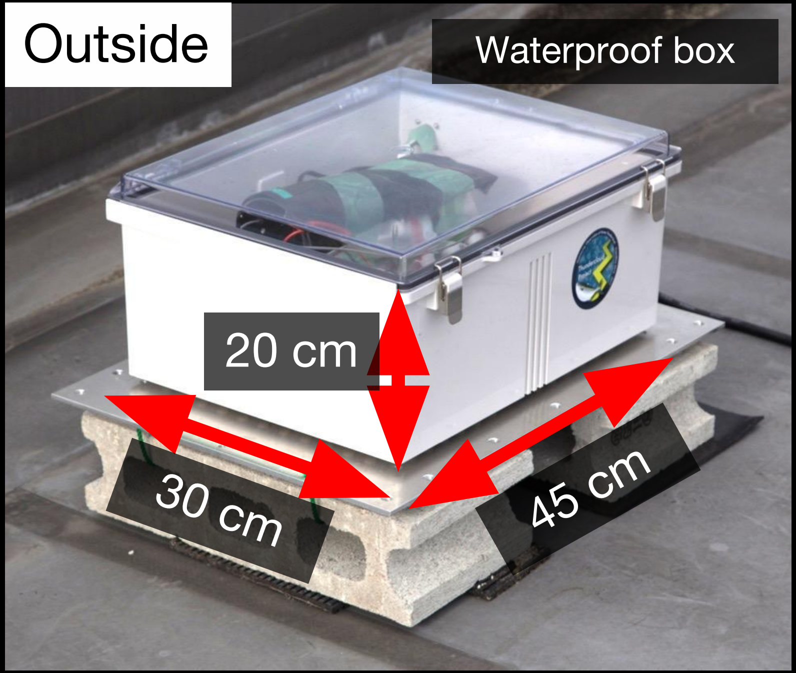
Compact DAQ system

- Photon by photon record with time and energy
- Controlled by Raspberry Pi 3
- All we need is included

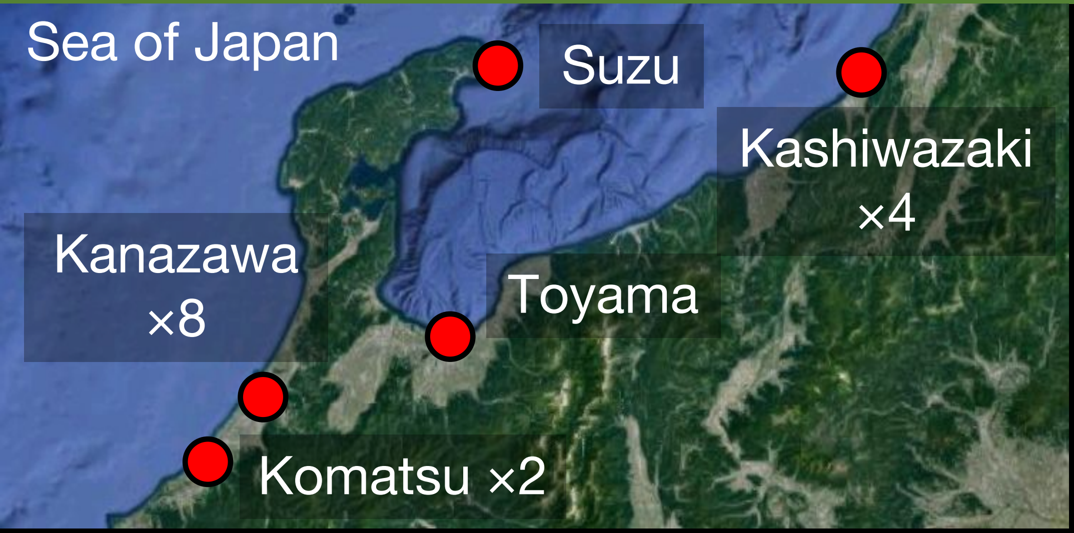
- 4 ch 12 bit 50 MHz ADC
- Charge amplifier
- High-voltage power supply
- GPS time tagging
- Environmental sensor

(Wada, Master Thesis 2017)

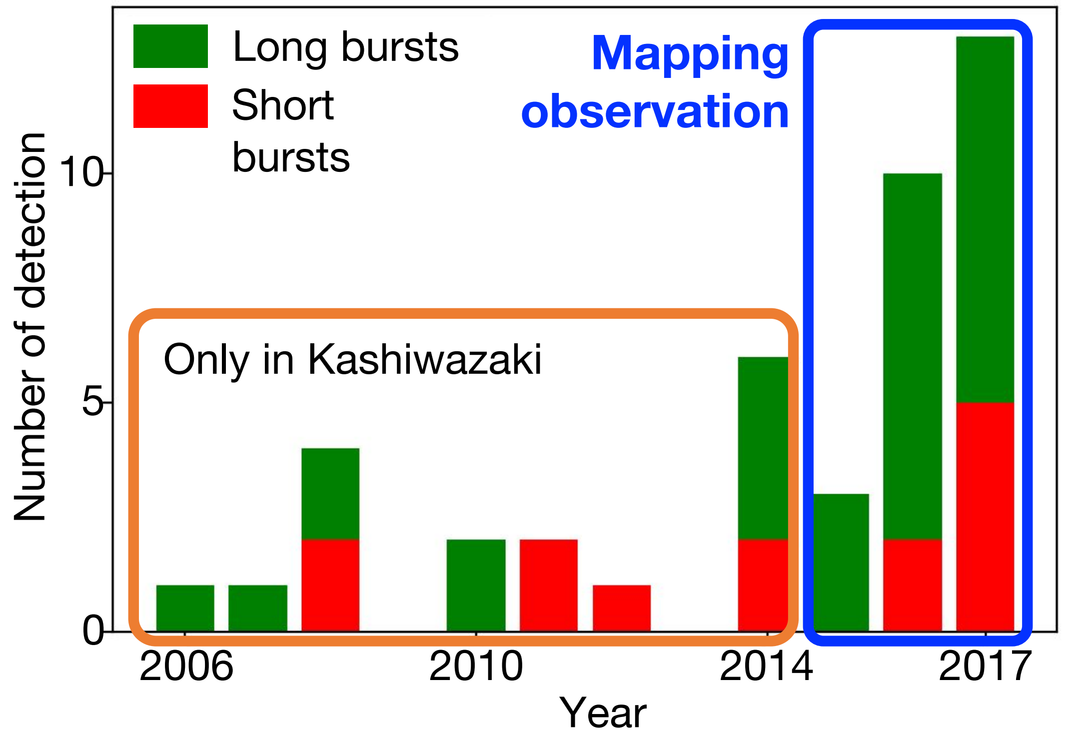




Deployment of Mapping Observation

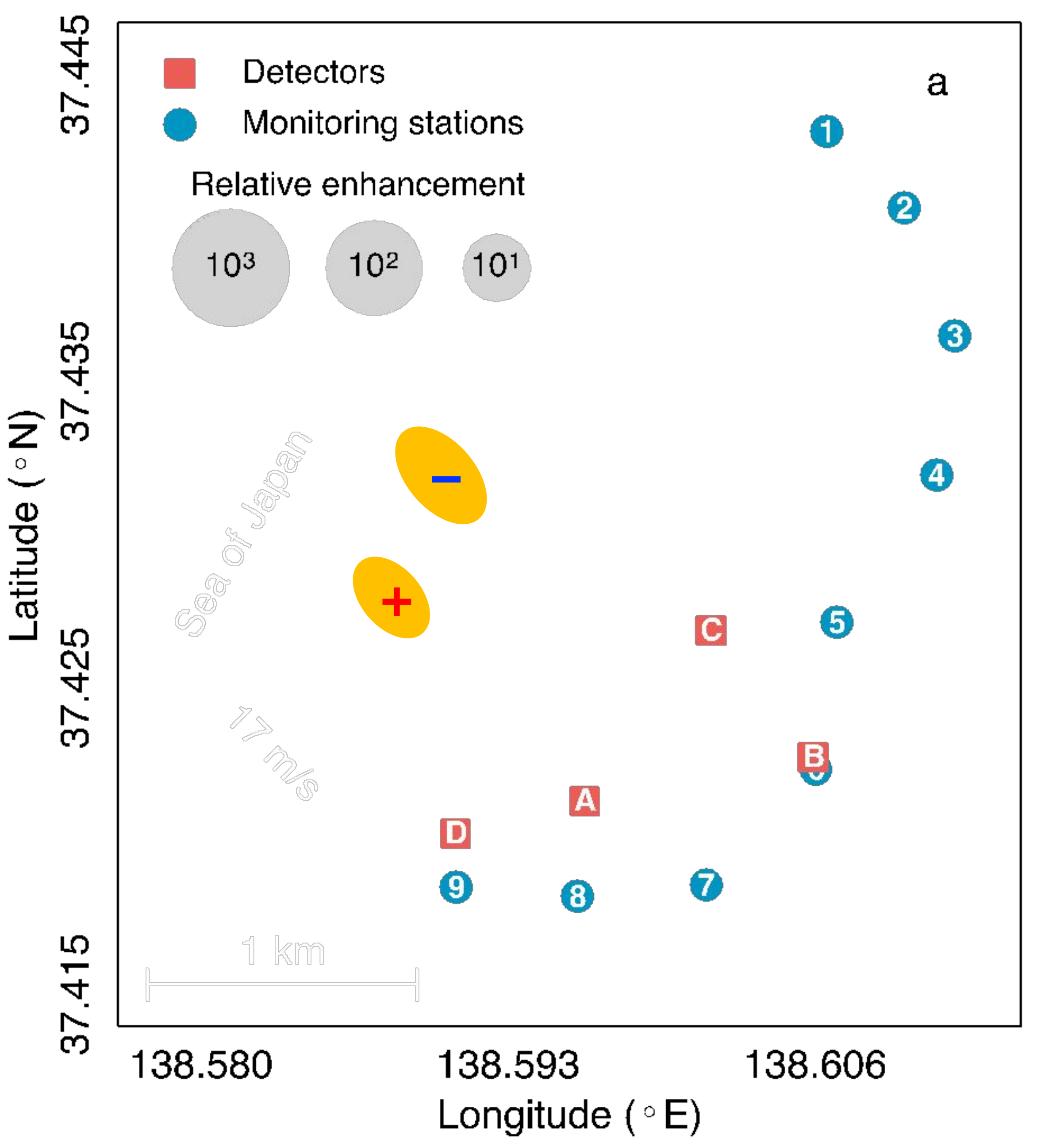


(c) Google, ZENRIN, Data Japan Hydrographic Association, Landsat/Copernicus, Data SIO, U.S. Navy, NGA, GEBCO



- Five observation areas along Sea of Japan
- Trying to increase detectors in Kanazawa
  - We hope 20-30 instruments in several years.
- Observation results are being accumulated.
  - The mapping observation successfully detect long/short bursts.
  - Statistical discussions on long bursts are ongoing.
- **Two important results**
  - Interpretation of short bursts (Enoto, et al., *Nature*, 551, 481-484, 2017)
  - Termination of a long burst (Wada, et al., *GRL*, 45, 5700-5707, 2018)

Detection of a Short Burst in Kashiwazaki (Enoto+2017)



- Lightning discharge in Kashiwazaki at 17:34:06 JST, 6th February 2017.
- Japanese Lightning Detection Network and an ELF receiver detected CG discharges. (ELF observation with M. Sato)
- Our 4 detectors and 9 monitoring stations recorded a short burst with the lightning.

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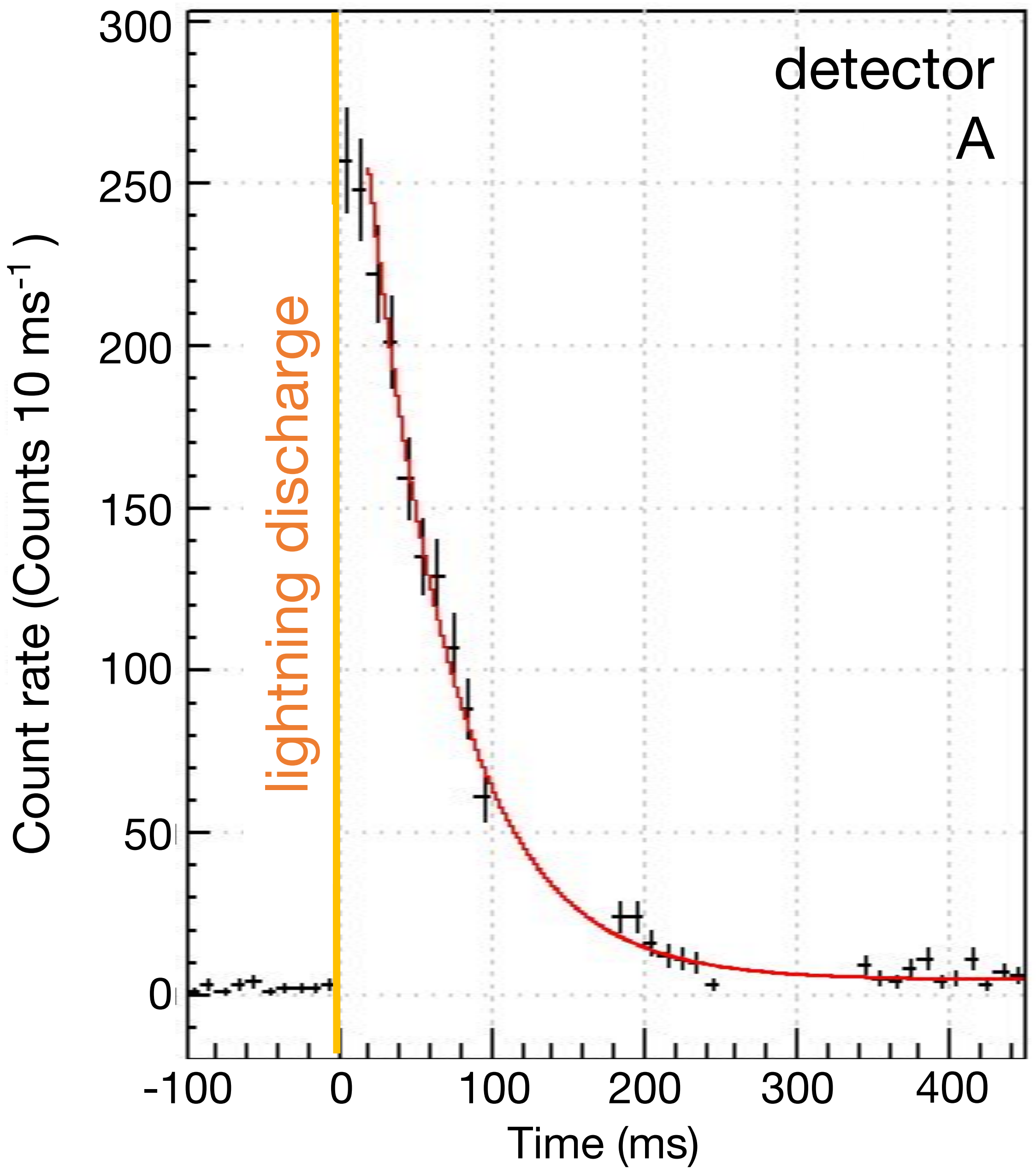

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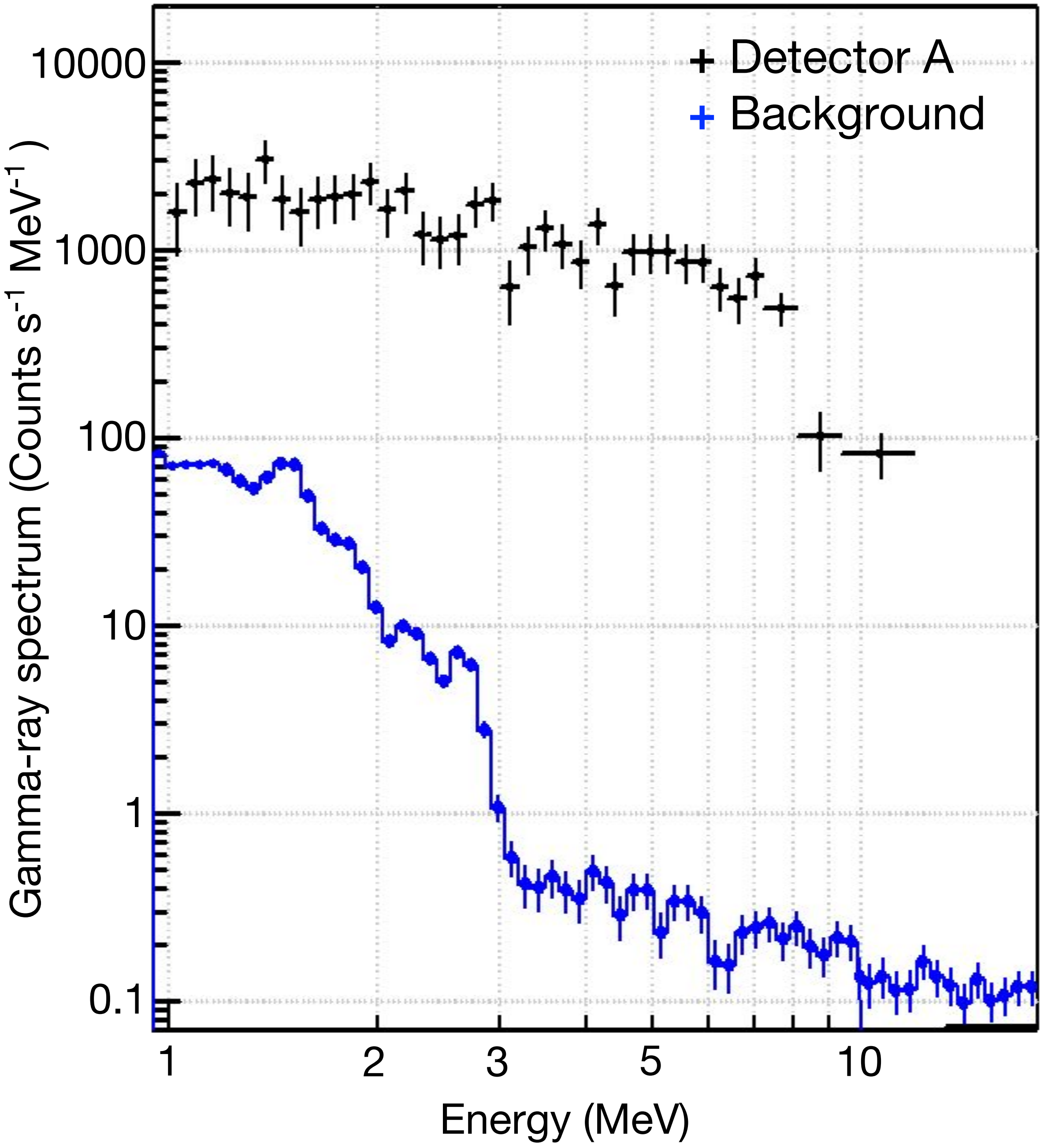

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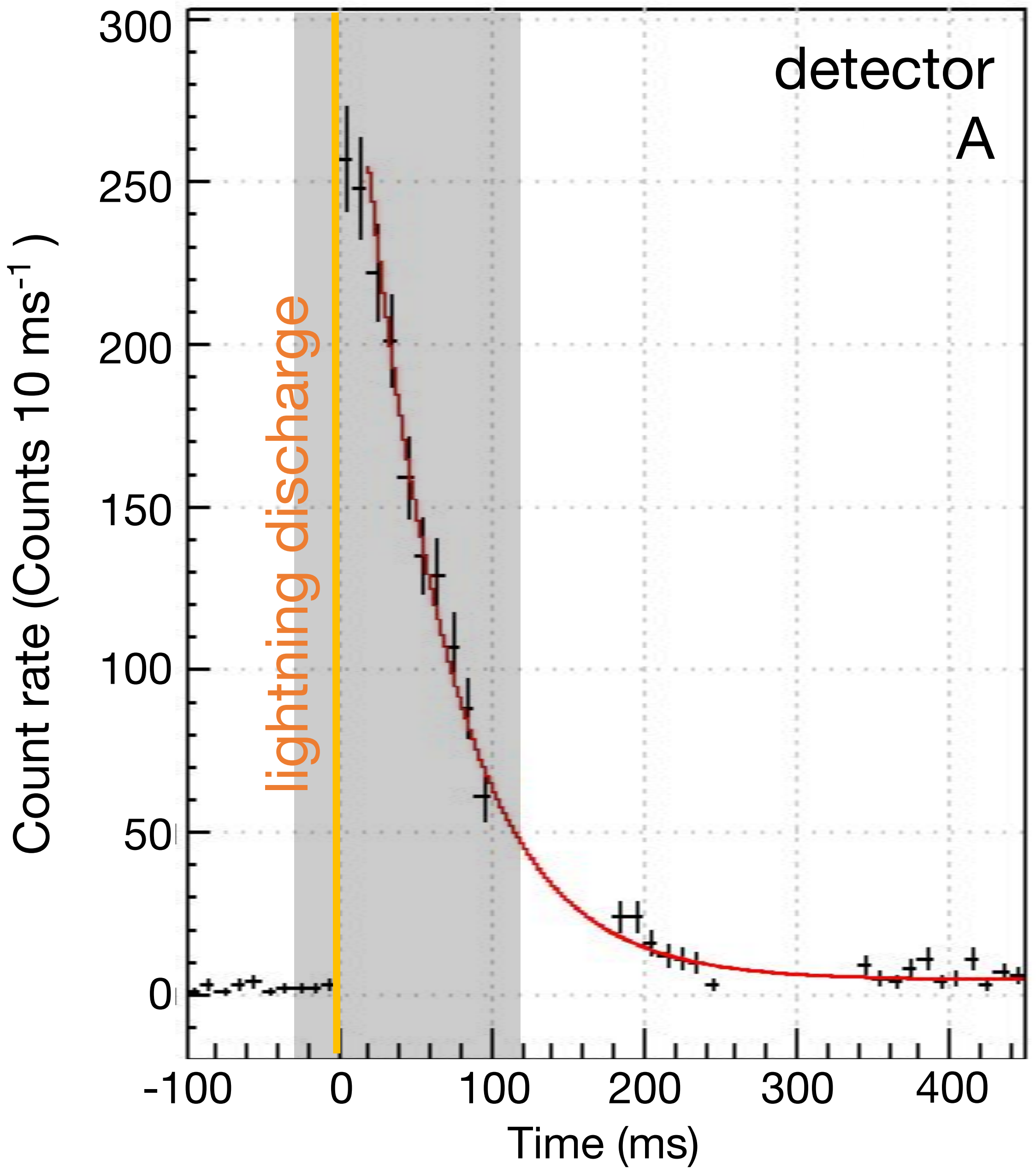
- Energy spectrum extends up to 10 MeV.
  - Sharp cutoff at ~10 MeV
  - Different from Bremsstrahlung

Signature of a Downward TGF (Enoto+2017)



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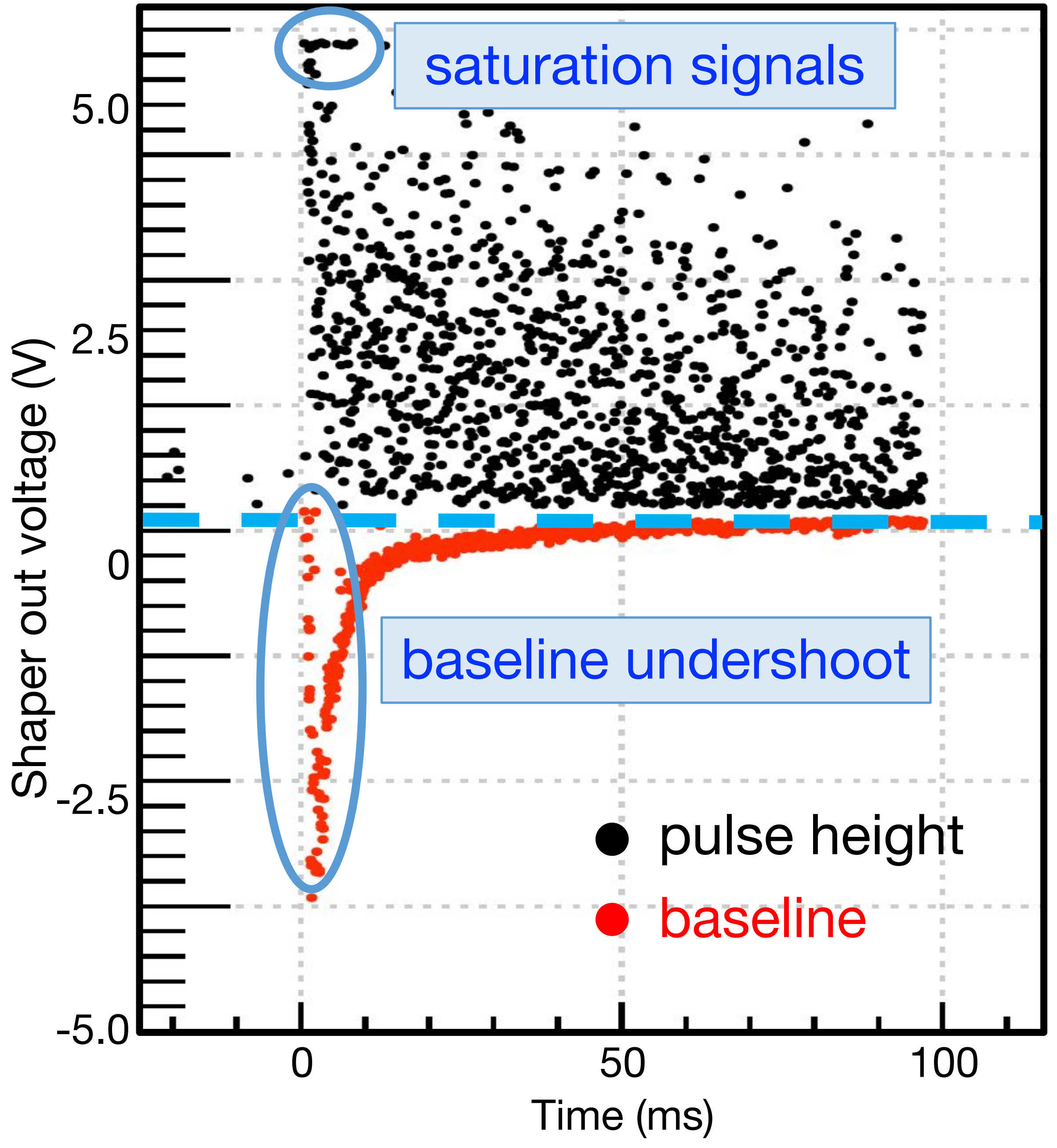

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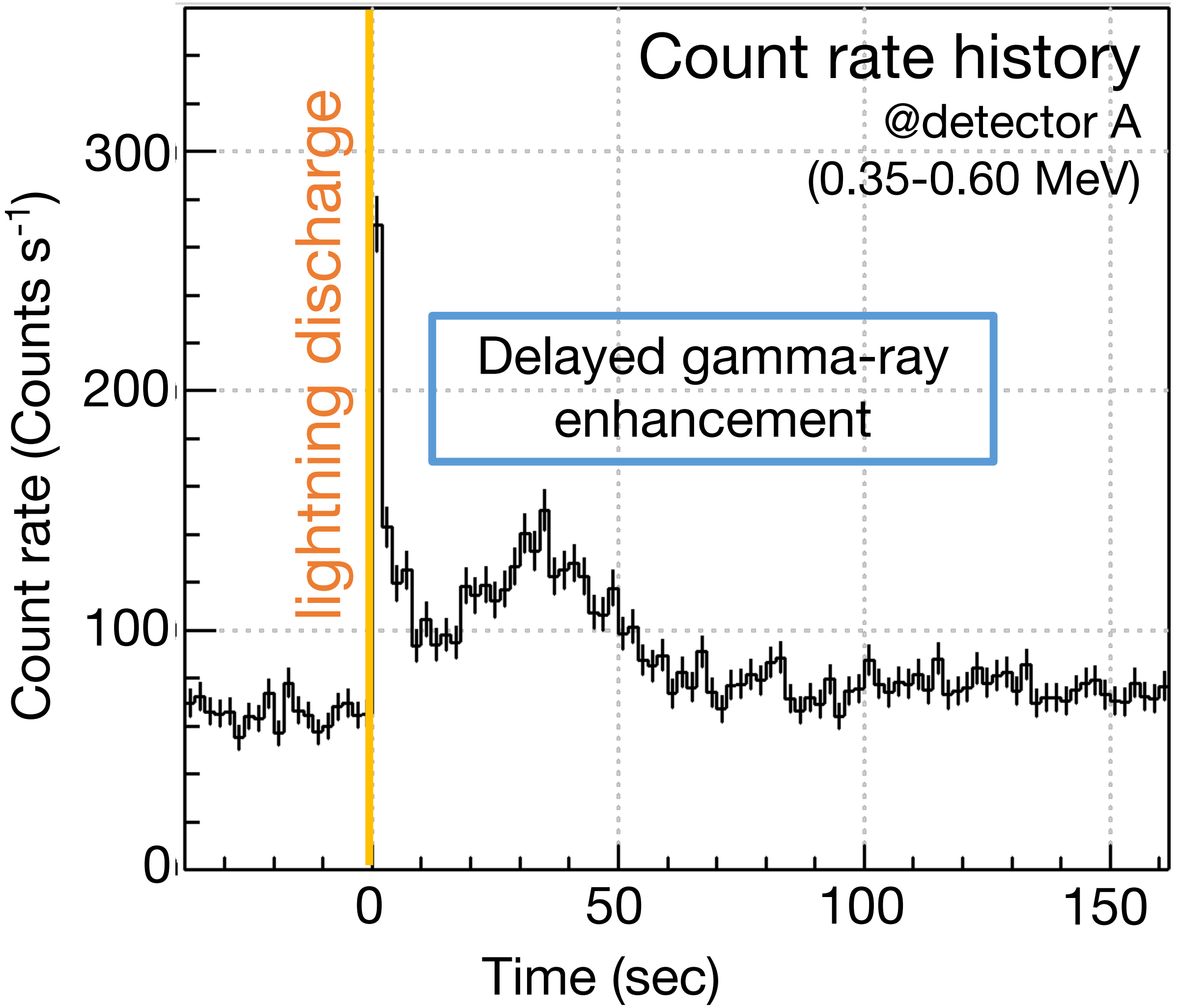
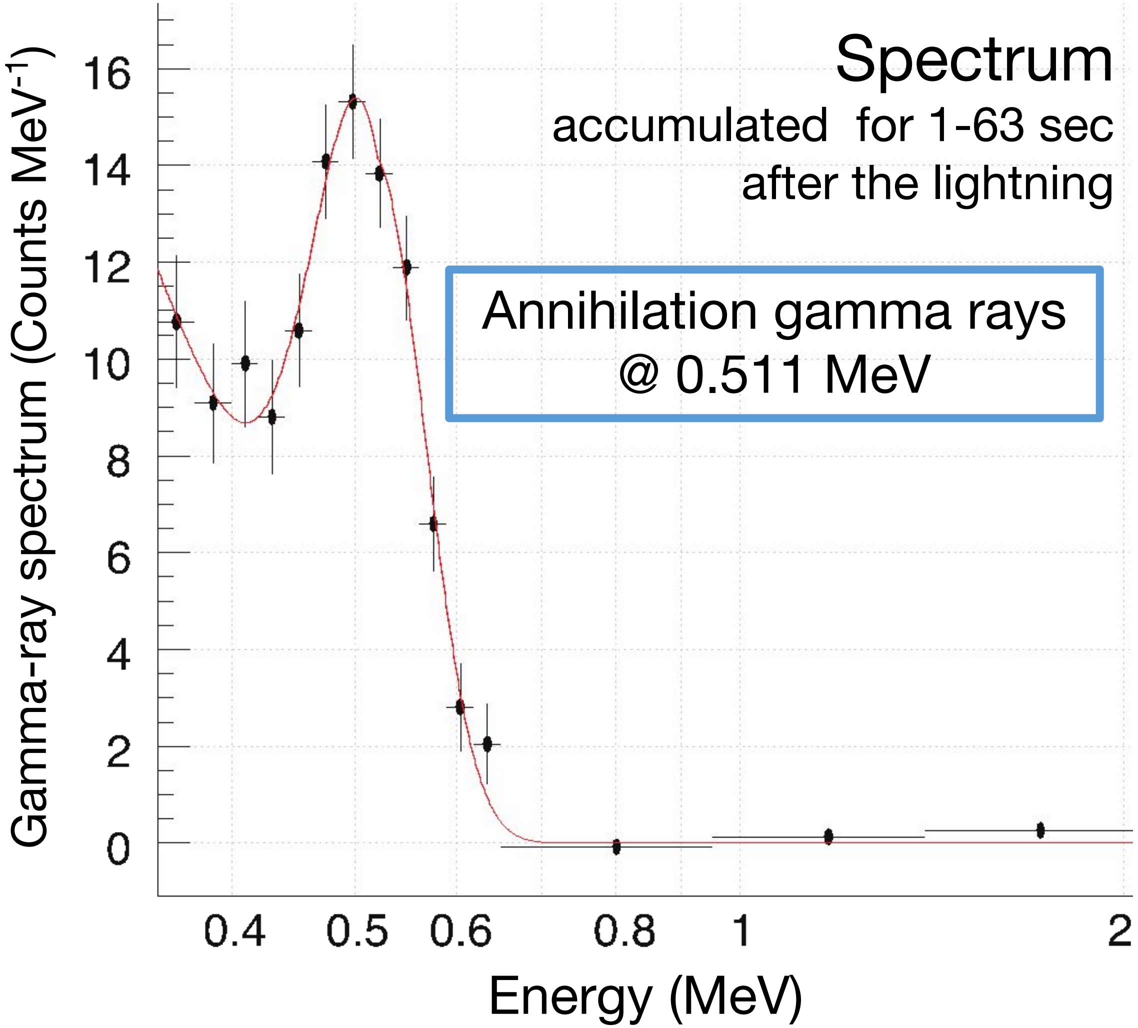
- Energy spectrum extends up to 10 MeV.
  - Sharp cutoff at ~10 MeV
  - Different from Bremsstrahlung
- Base line of analog output were disturbed.
  - Large energy deposit into scintillators?
  - **<u>Indicating a downward TGF.</u>**

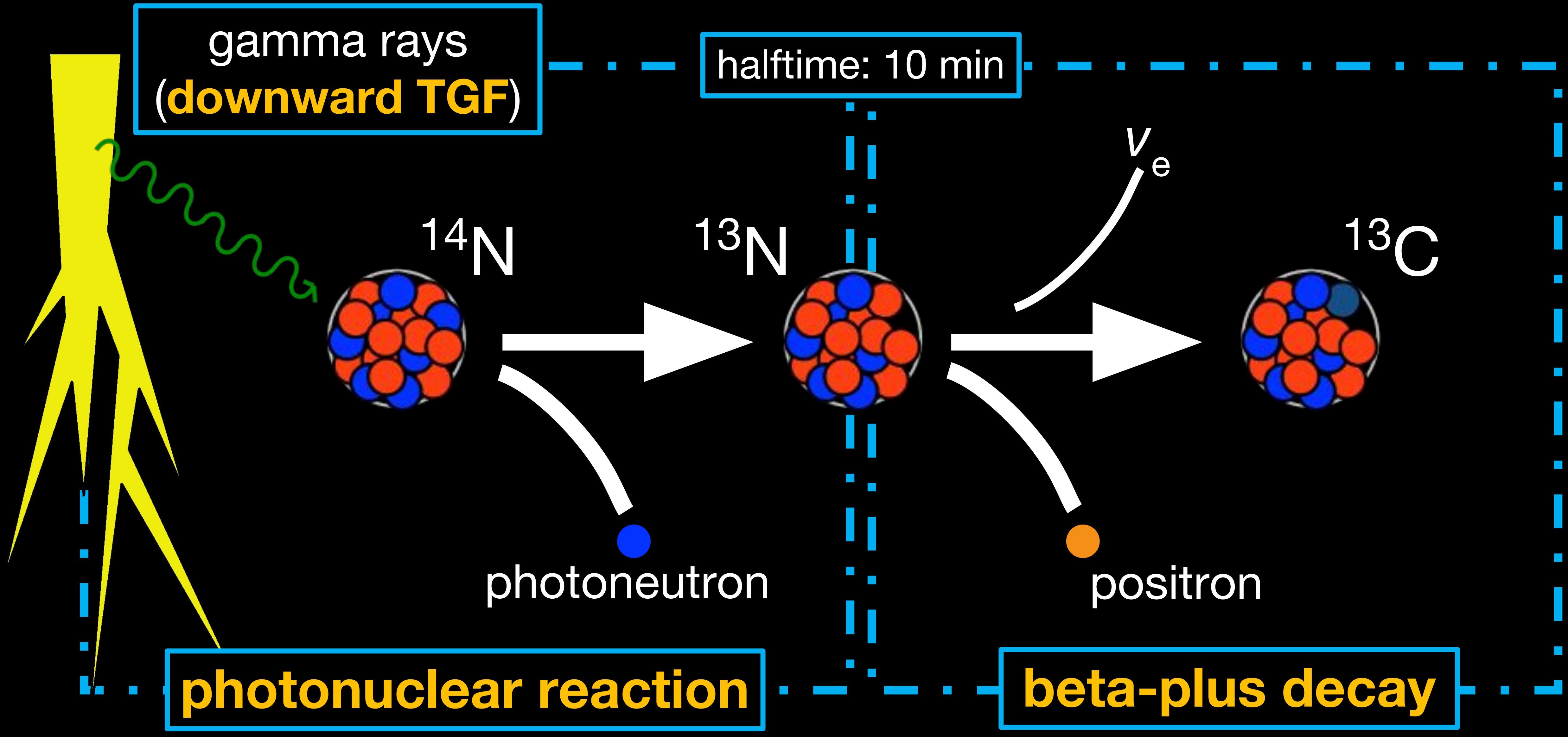
Delayed Annihilation Gamma Rays (Enoto+2017)





- 511 keV emission peaking at 35 sec and lasting for ~1 min.
- No significant high energy photons provoking pair creation.

Photonuclear Reactions by Lightning Discharge (Enoto+2017)



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

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

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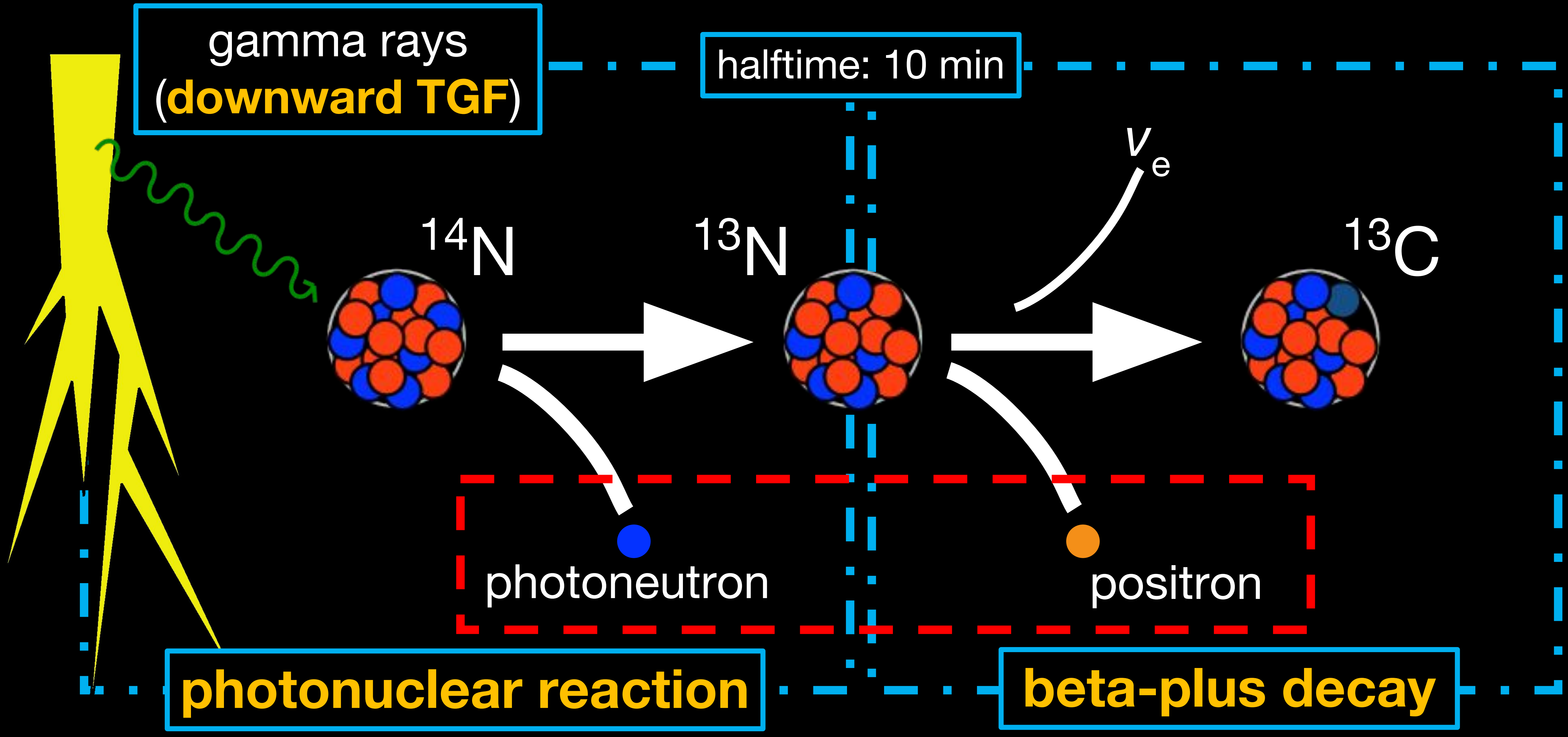

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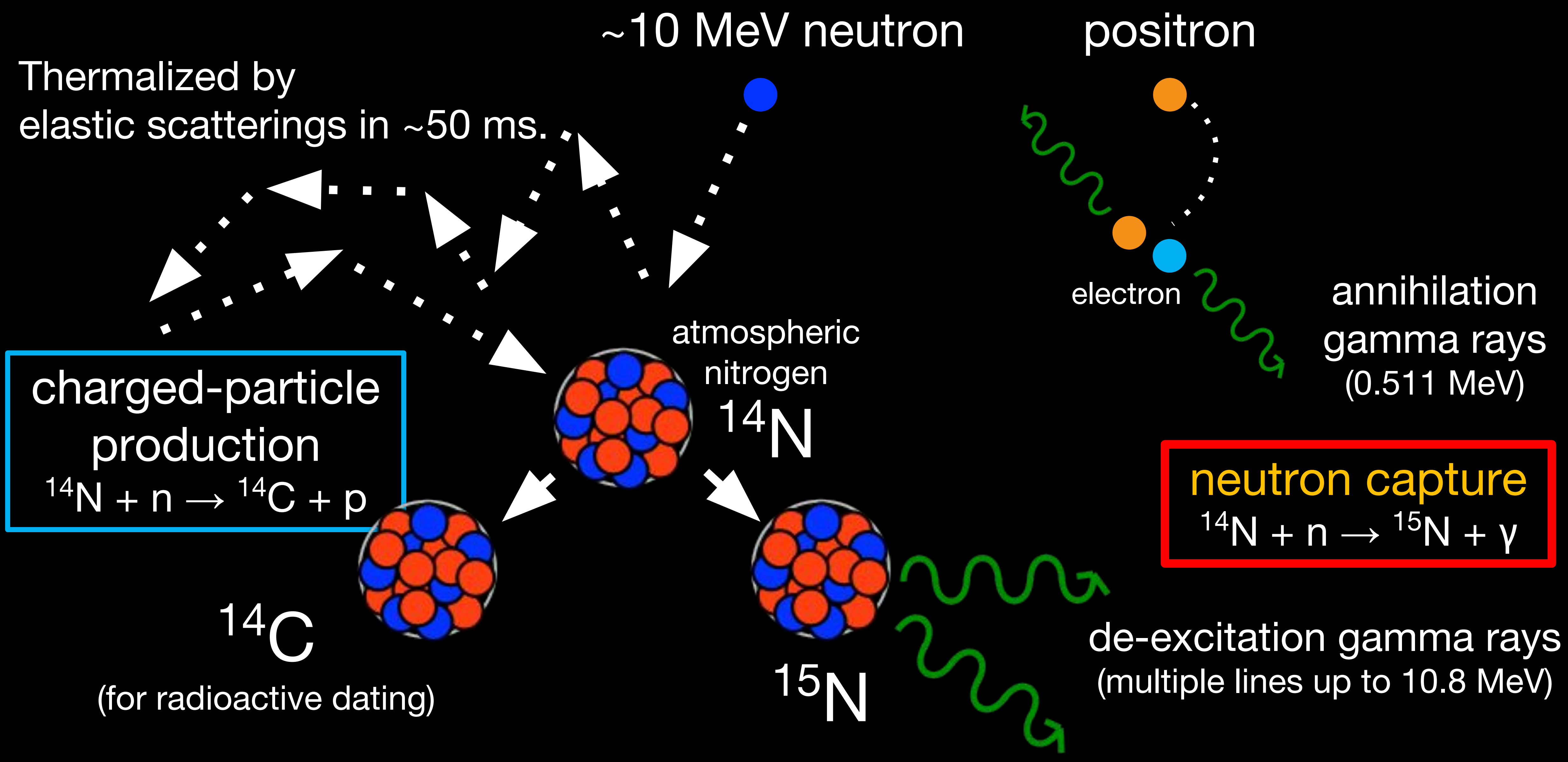
Reactions of Neutron / Positron in the Atmosphere (Enoto+2017)



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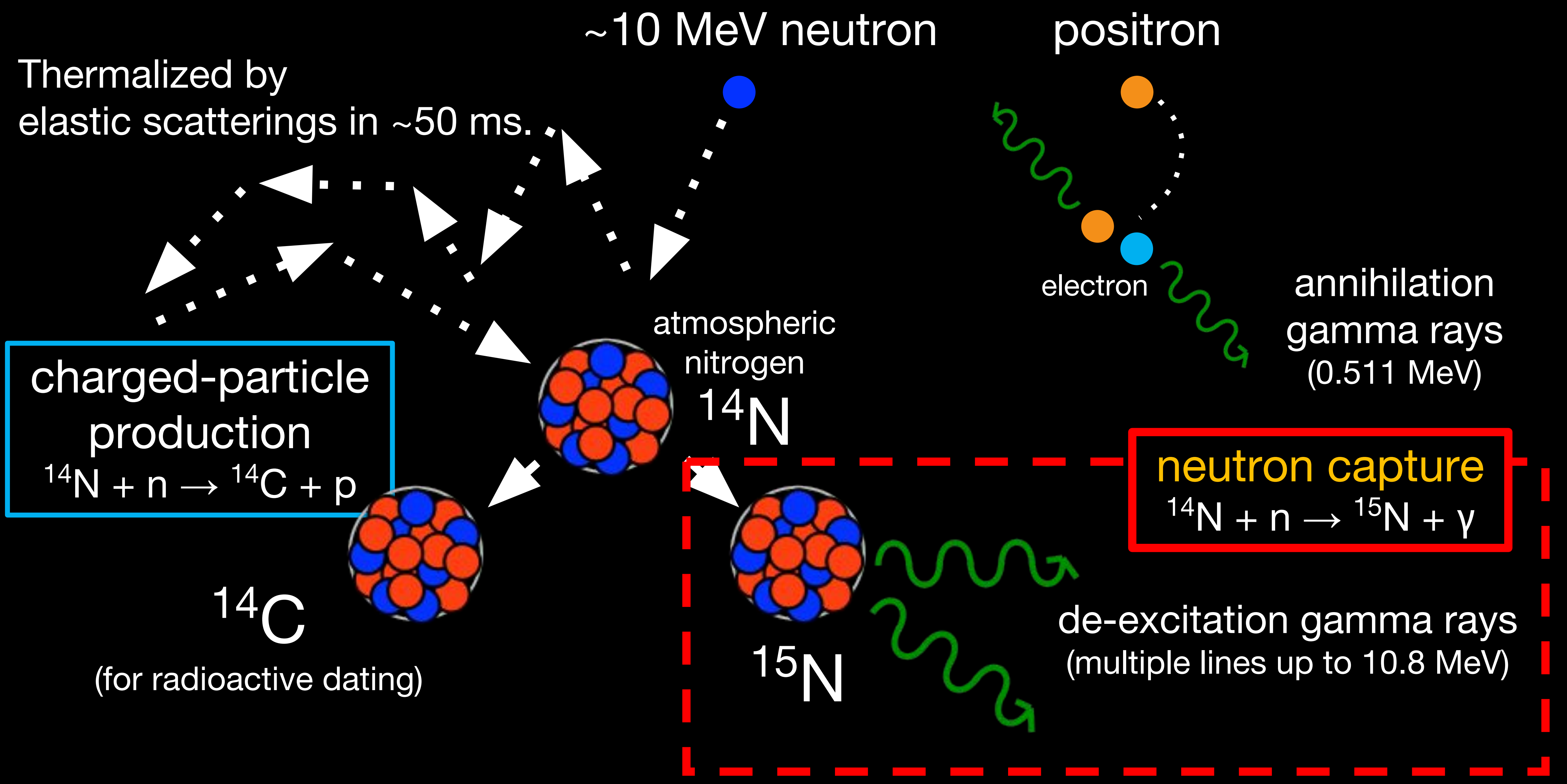
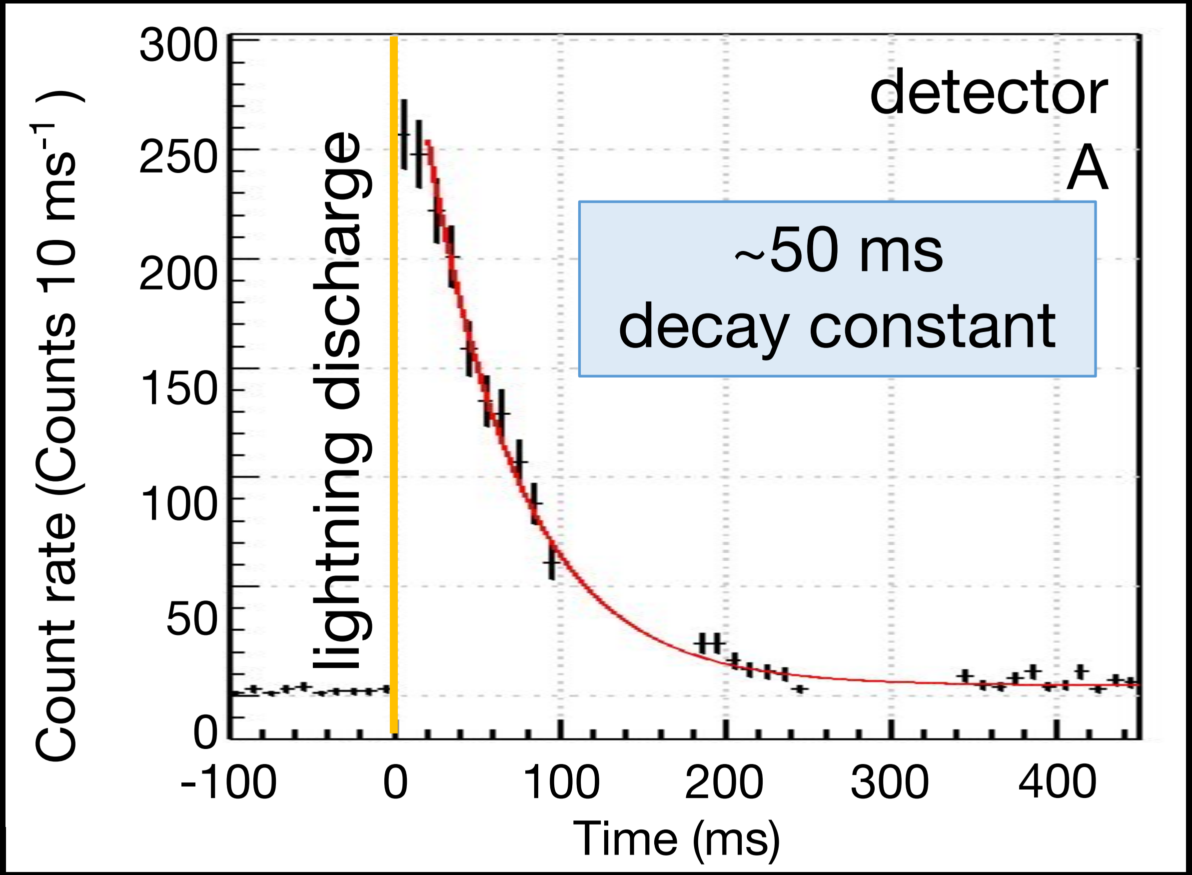
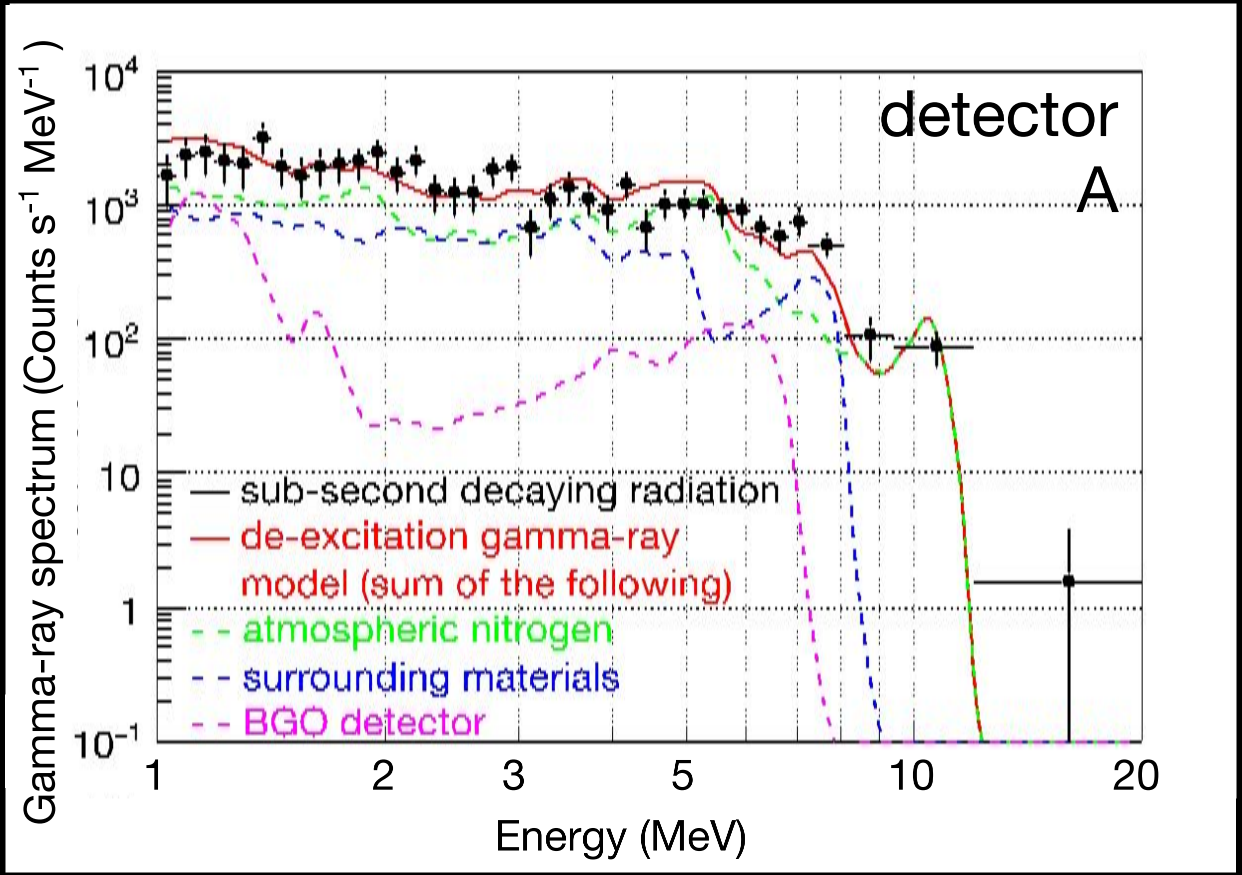


De-Excitation Gamma Rays of Neutron Captures (Enoto+2017)





Consistent with thermalization time scale (~50 ms).

Many lines of de-excitation gamma rays from neutron capture.

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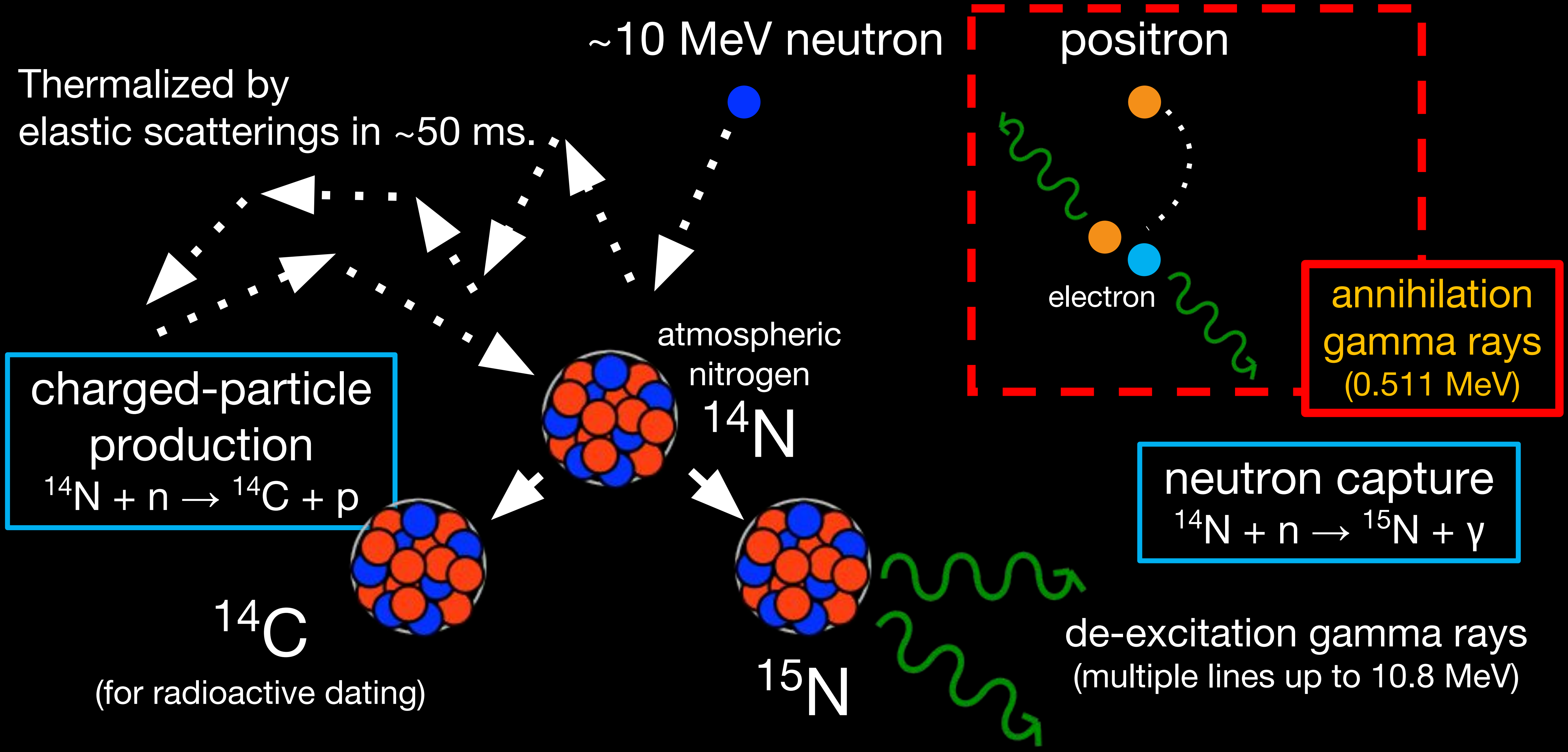
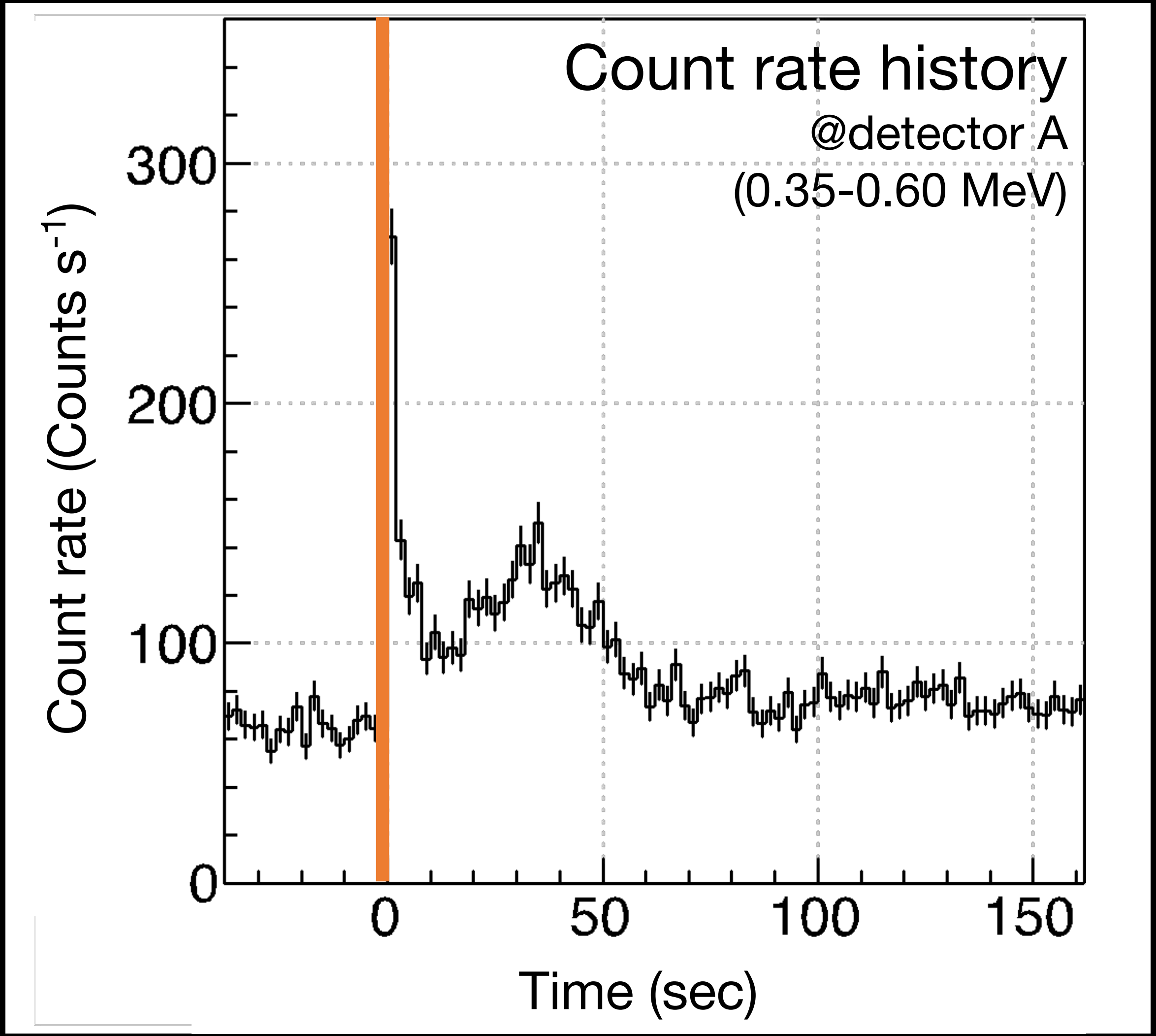
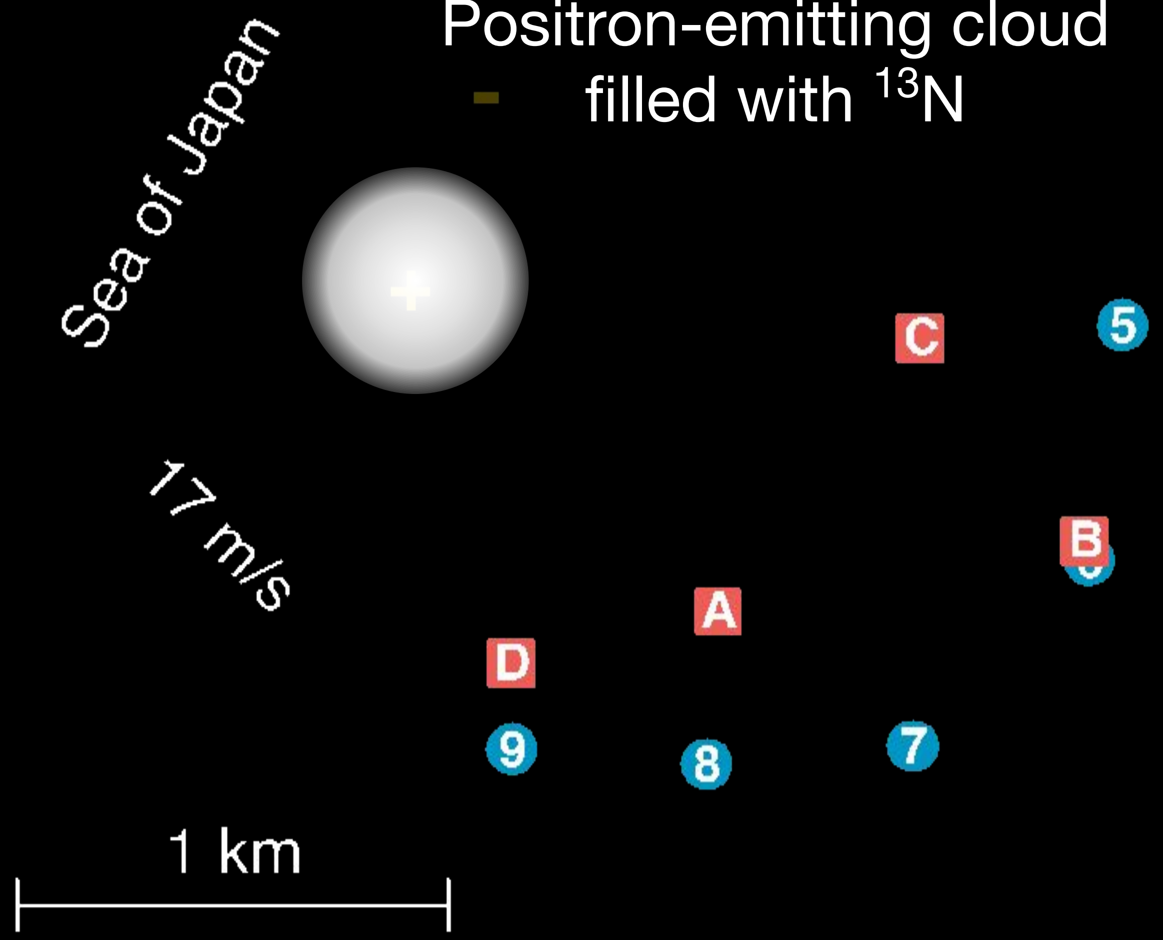


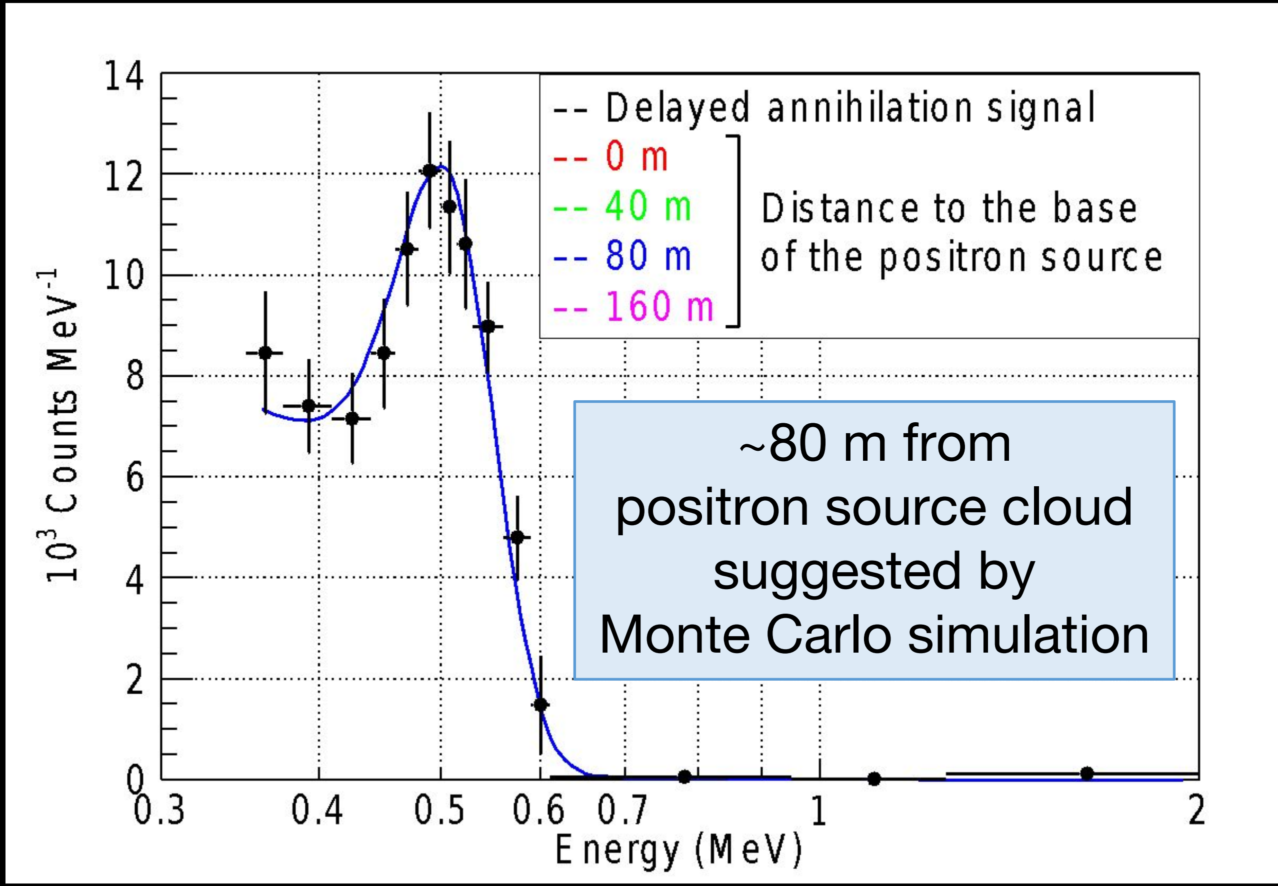
Positron-Emitting Cloud (Enoto+2017)

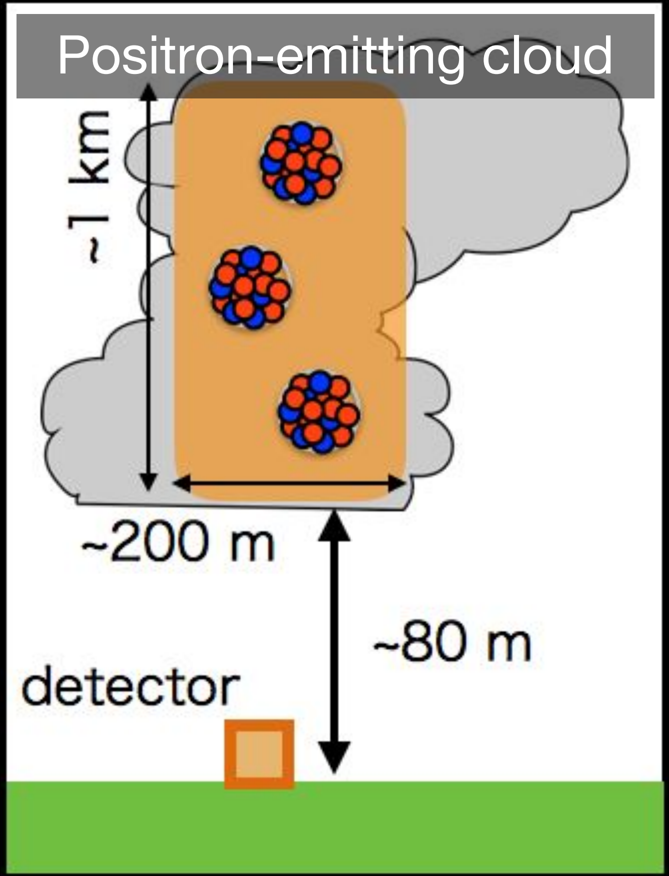




Cloud of ^{13}N and ^{15}O moved with ambient wind flow, and passed over detector A.
→ **Delayed annihilation signal**

Number of Photonuclear Reactions (Enoto+2017)

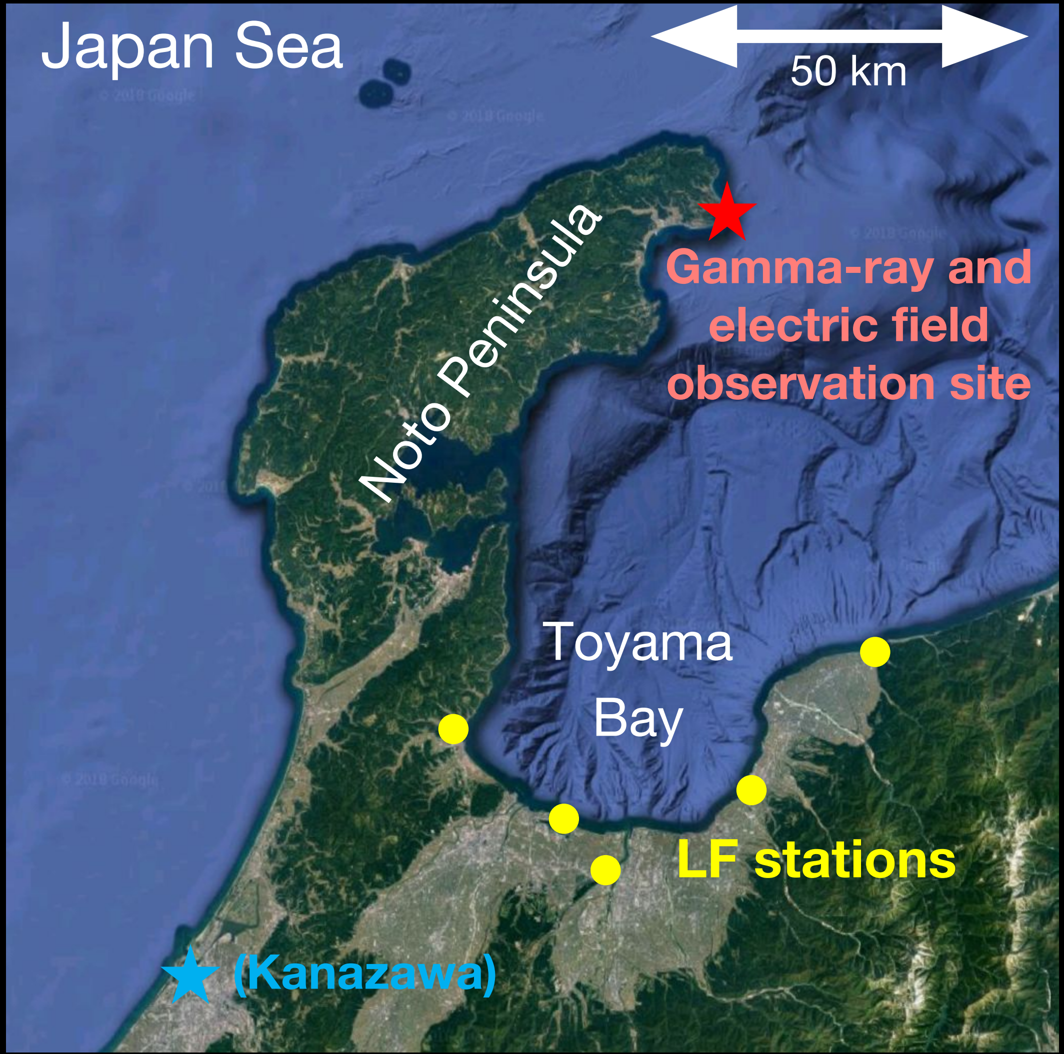




Monte Carlo simulation and a simplified cylindrical geometry derived
the lightning produced 4×10^{12} neutrons via photonuclear reactions.

Consistent with theoretical predictions and recent neutron observation.
($10^{11\text{-}15}$: Carlson et al. 2010, Babich et al. 2010) ($10^{12\text{-}13}$: Bowers et al. 2017)

Long Burst Terminated with Lightning Discharge (Wada+2018)



Observation in Suzu (2016-2017 winter season)

GROWTH detector
- 3 inch BGO scintillator

Lightning mapping in LF
- 5 stations along Toyama Bay

- Flat plate antenna
- 800 Hz – 500 kHz

With Y.Nakamura (KCCT) & T.Morimoto (Kinki Univ.)

GODOT detector With G.S.Bowers & D.M.Smith (UC Santa Cruz)
- 5 inch NaI scintillator

Atmospheric electric field measurement
- Boltek EFM-100

With M.Kamogawa (Tokyo Gakugei Univ.)

Simultaneous monitoring of gamma-ray, radio wave, atmospheric electric field

Beginning of collaborative observation campaigns in winter thunderstorms

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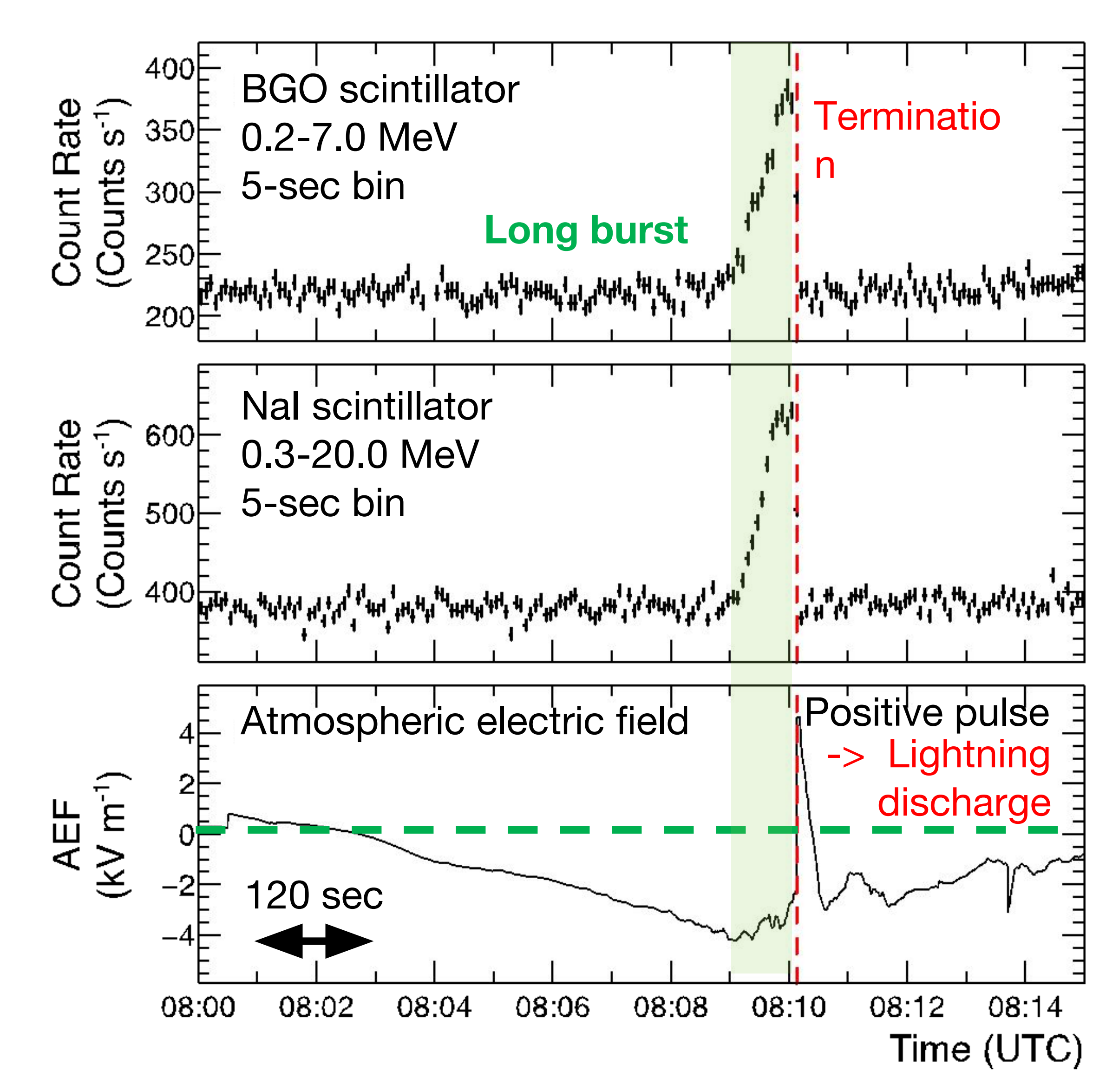
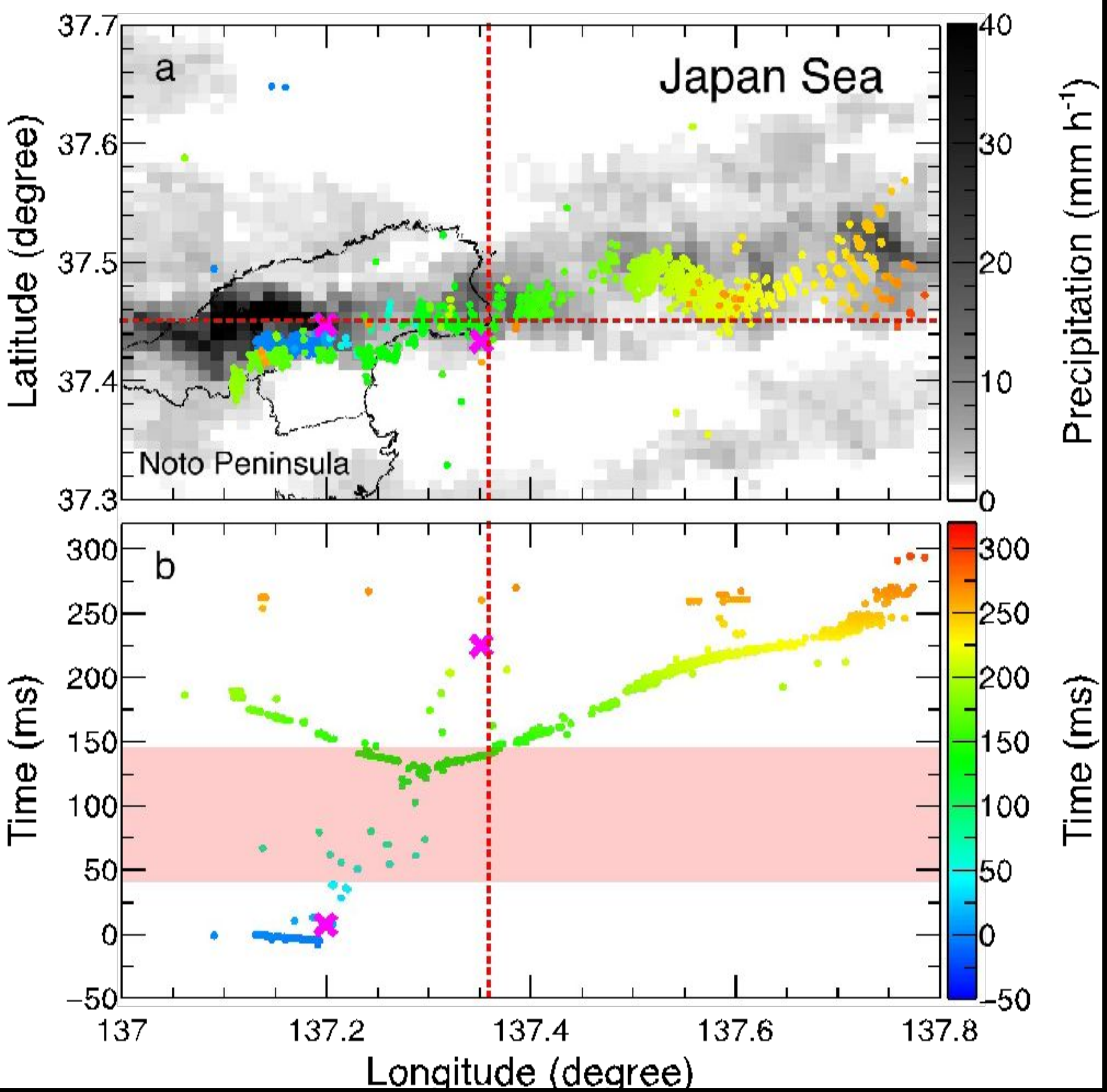


- Long burst lasting for ~1 minute on 11th February 2017.
- Negatively-charged cloud approaching.
- **The long burst was terminated with a lightning discharge at 08:10:08 UTC.**

Long Burst Terminated with Lightning Discharge (Wada+2018)



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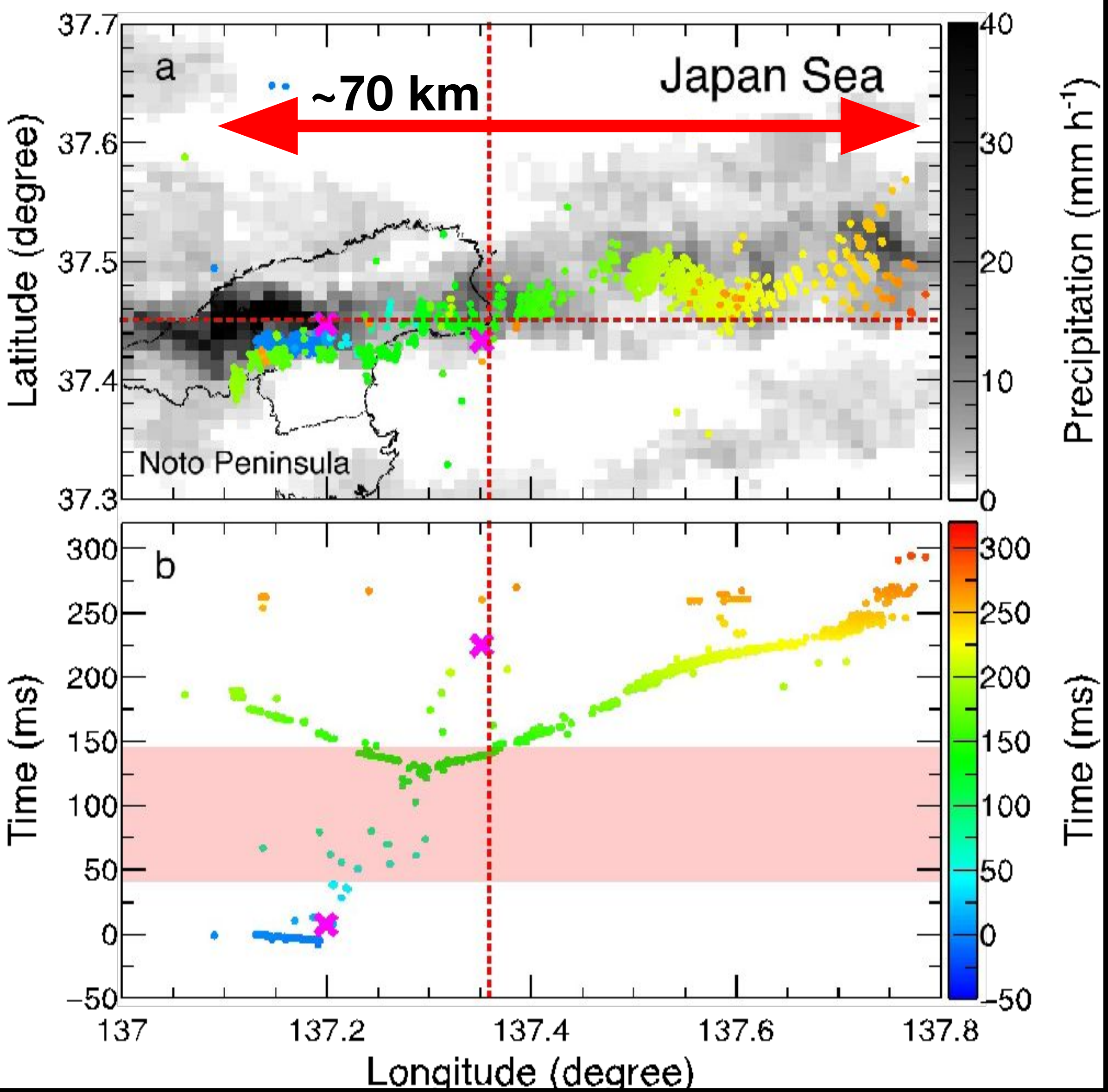

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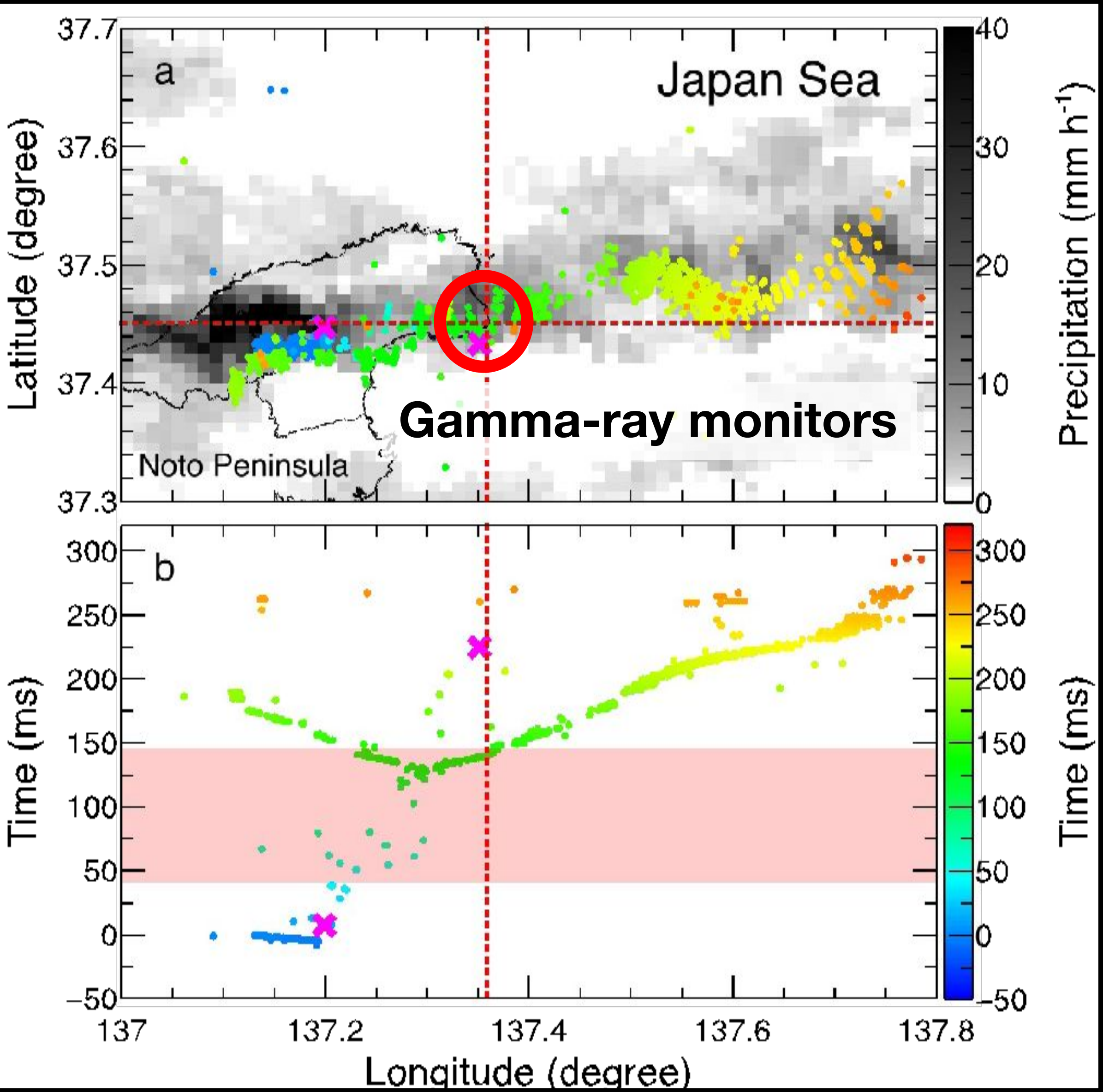

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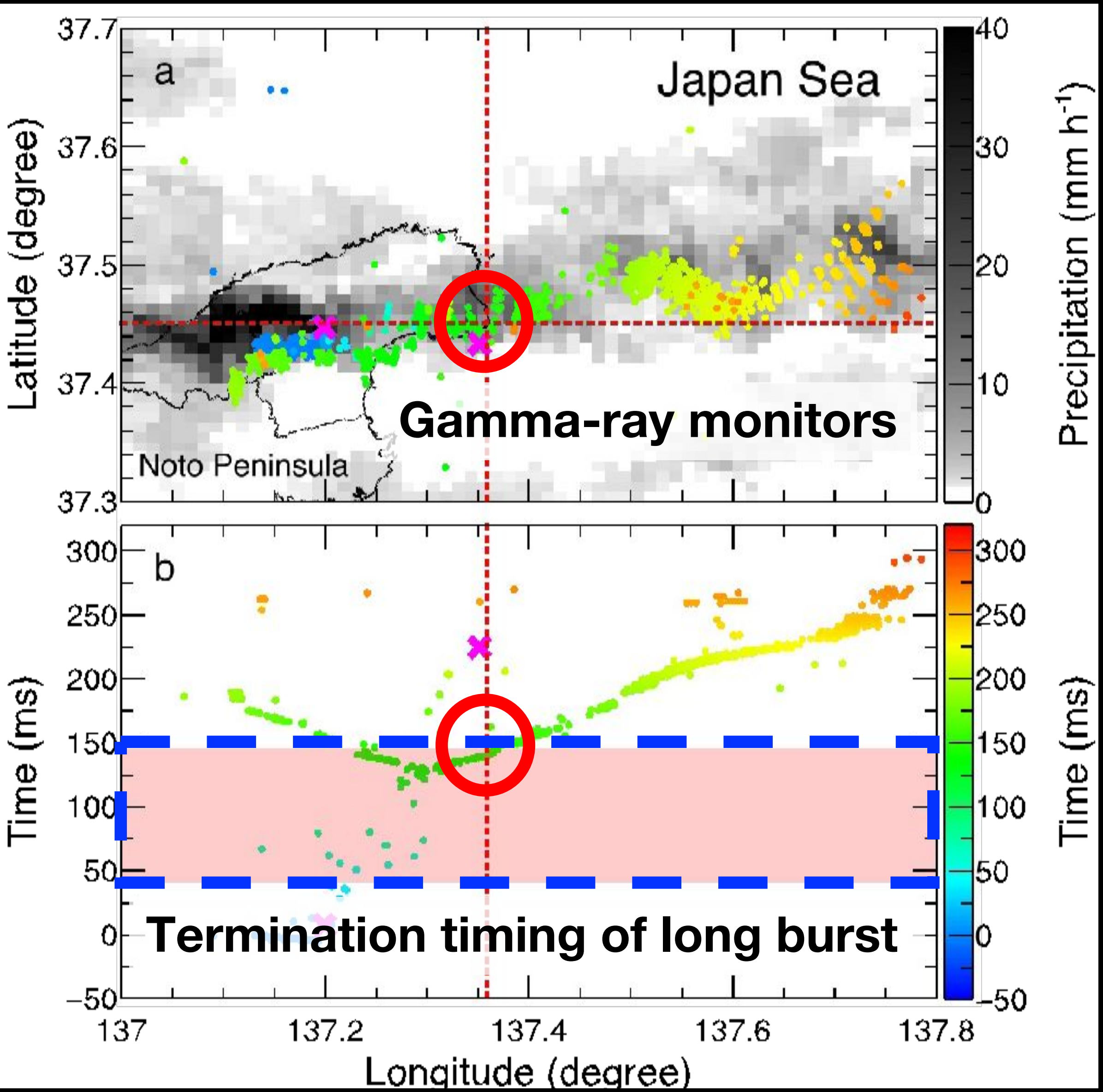

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The burst-inducing region was destroyed by the leader development.

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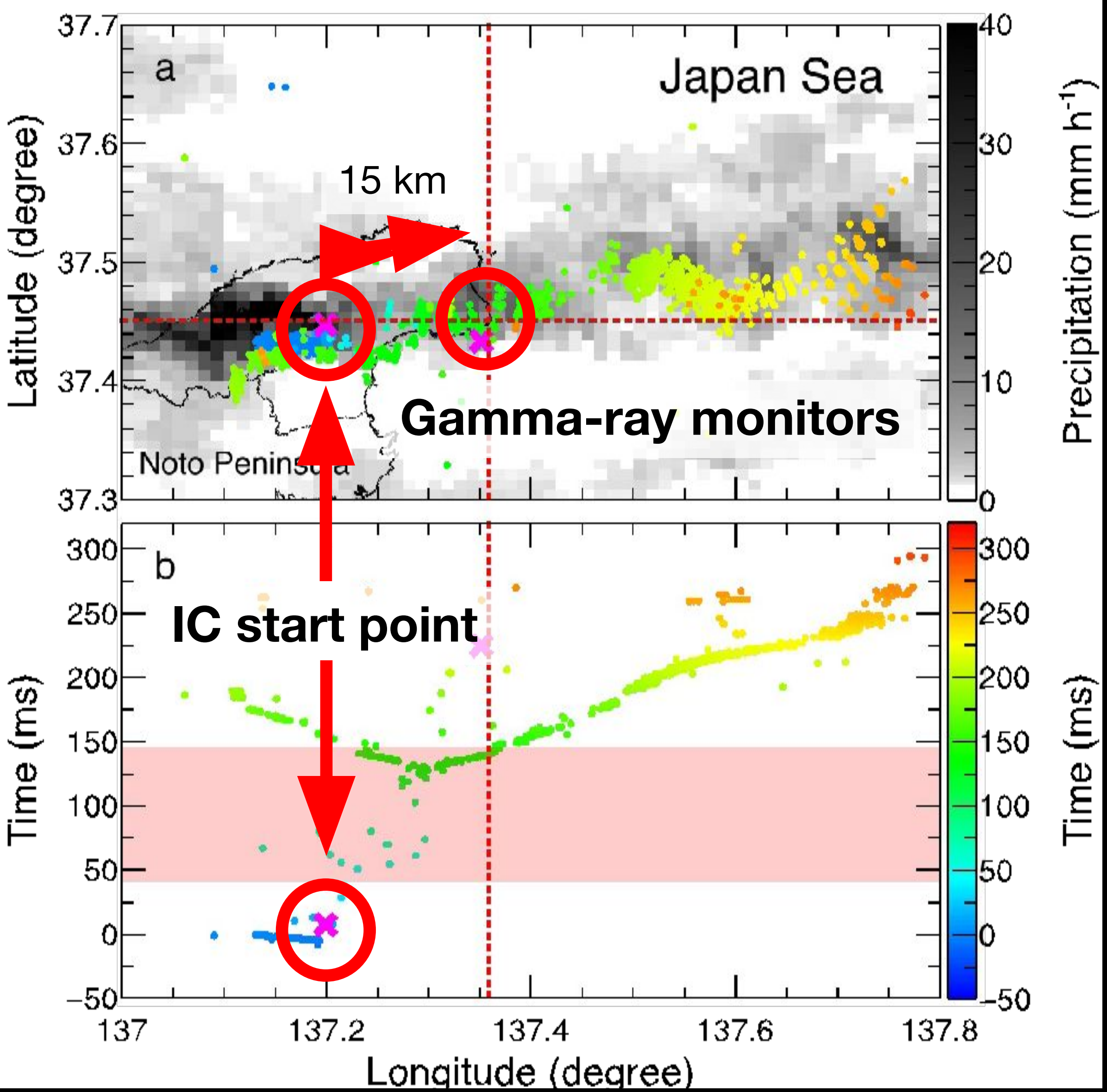

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- The present long burst was not involved in lightning initiation.

Conclusion and Future Prospects

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- We are developing mapping observation campaigns of winter thunderstorms in Japan.
- More than 10 portable radiation detectors have been developed and deployed.
- High-energy events has been successfully obtained by the campaign since 2015.
- We demonstrated photonuclear reactions triggered by lightning discharge.
- Collaborative observation enables us to access keys of long bursts.
- Winter thunderstorms in Japan will give us more fruitful scientific results!

Future prospects

- We will complete installation of >20 detectors in Kanazawa within several years.
- We are promoting collaboration of gamma-ray, radio, electric field measurements essential not only for long bursts, but also for short bursts as well as downward TGFs.
- Ground-level detection of TGFs will play an important role for TGF sciences as well as detection by current and future satellite missions (Fermi, ASIM, Taranis...)

Golden Age of High-Energy Atmospheric Physics!