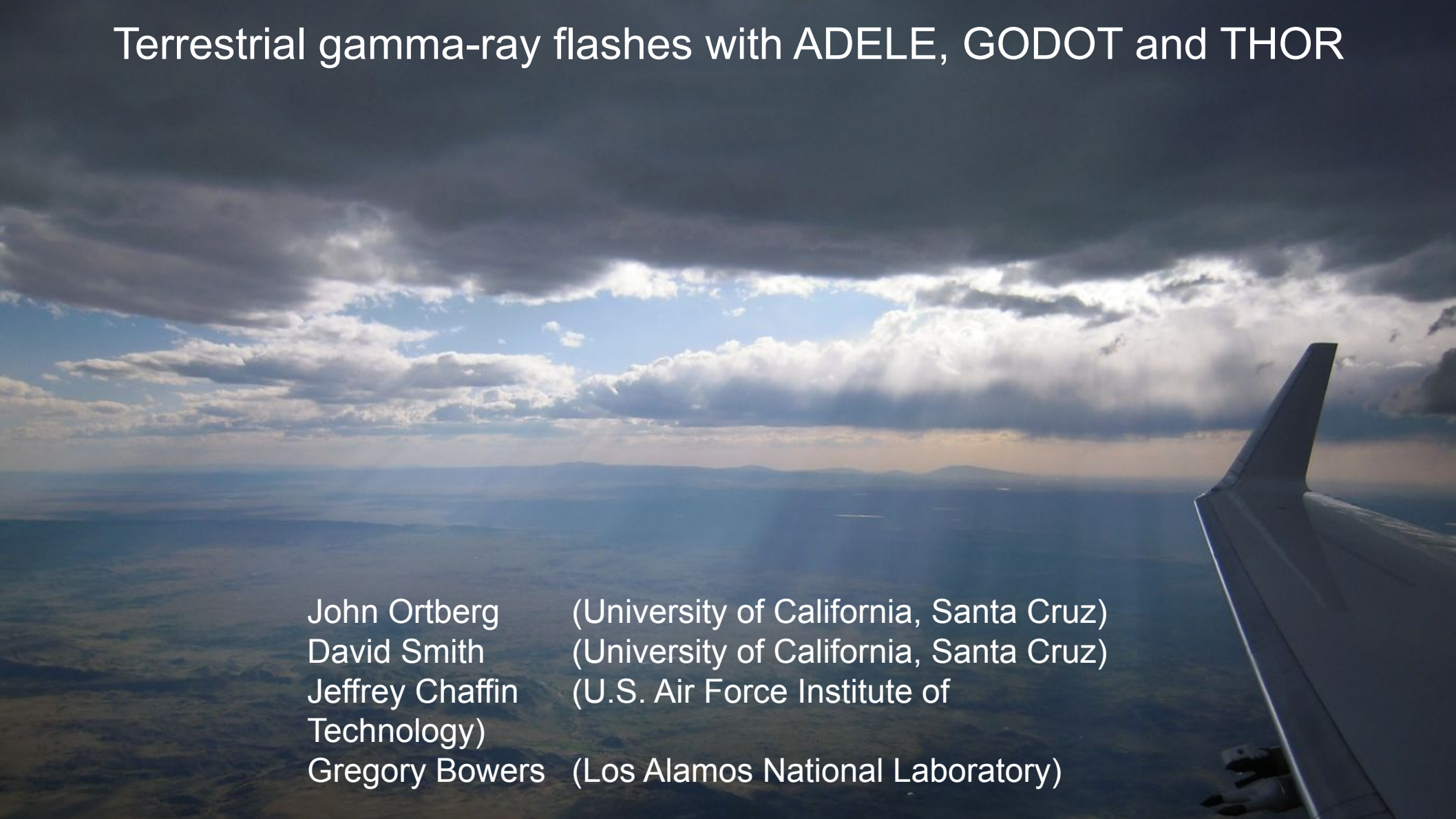
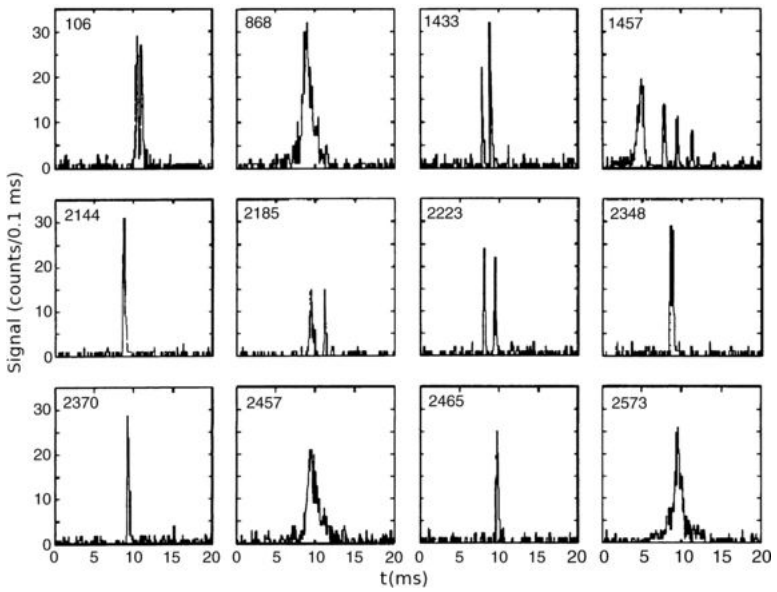
Terrestrial gamma-ray flashes with ADELE, GODOT and THOR

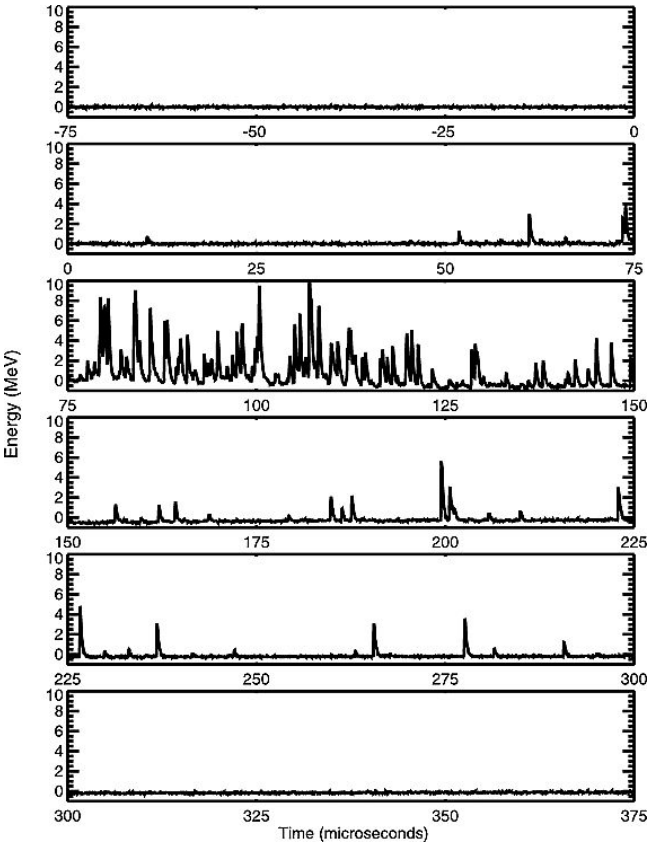


John Ortberg (University of California, Santa Cruz)
David Smith (University of California, Santa Cruz)
Jeffrey Chaffin (U.S. Air Force Institute of Technology)
Gregory Bowers (Los Alamos National Laboratory)

By 2007: Many upward TGFs seen from space



One TGF seen from the ground
(Dwyer et a. 2004)



Detector development at U.C. Santa Cruz, 2006-present

For aircraft and ground observations

ADELE 2009, 2015 flights, USA

- Large and small detectors for dynamic range

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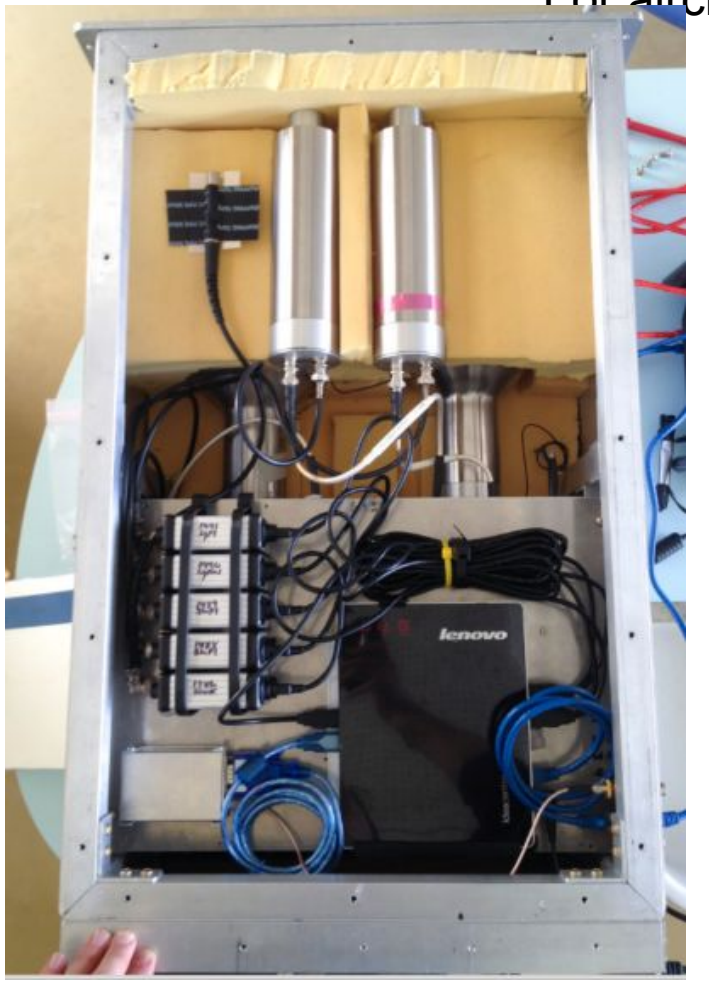
- Up/down directionality (2009 only)

Detector development at U.C. Santa Cruz,
2007-present

For aircraft and ground observations



GODOT 2014-present, Japan
Retained these characteristics of ADELE:

- Large and small detectors for dynamic range
- Plastic scintillators for high throughput / low cost
- NaI scintillator for spectroscopy
- **Plus:**
- Photon list data mode

Detector development at U.C. Santa Cruz, 2007-present

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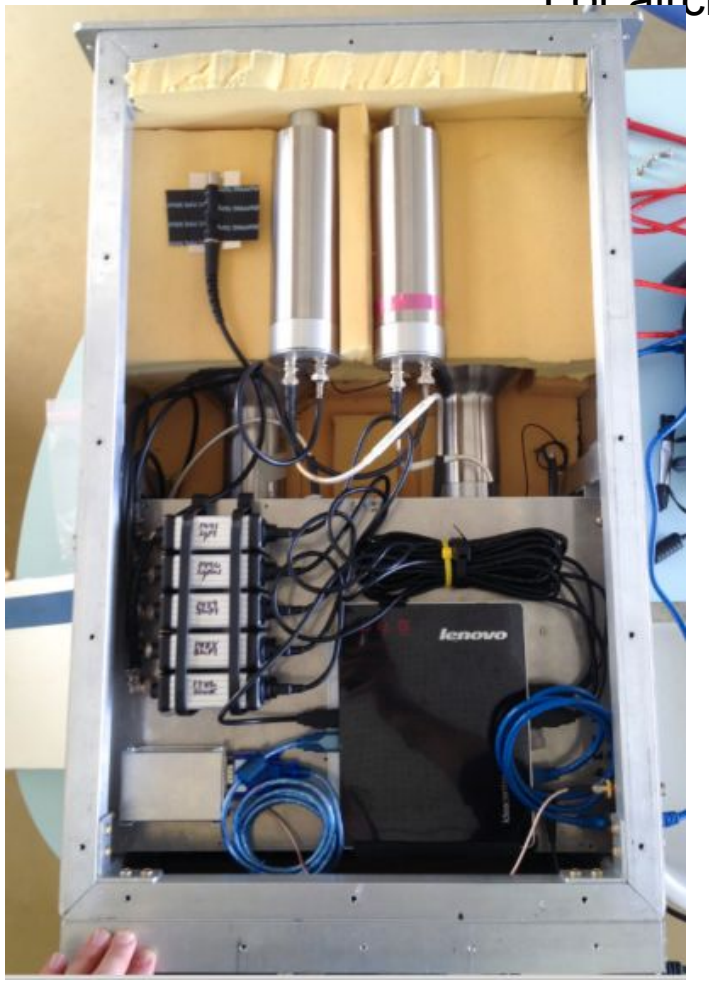

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- 4096 energy channels
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Detector development at U.C. Santa Cruz, 2007-present

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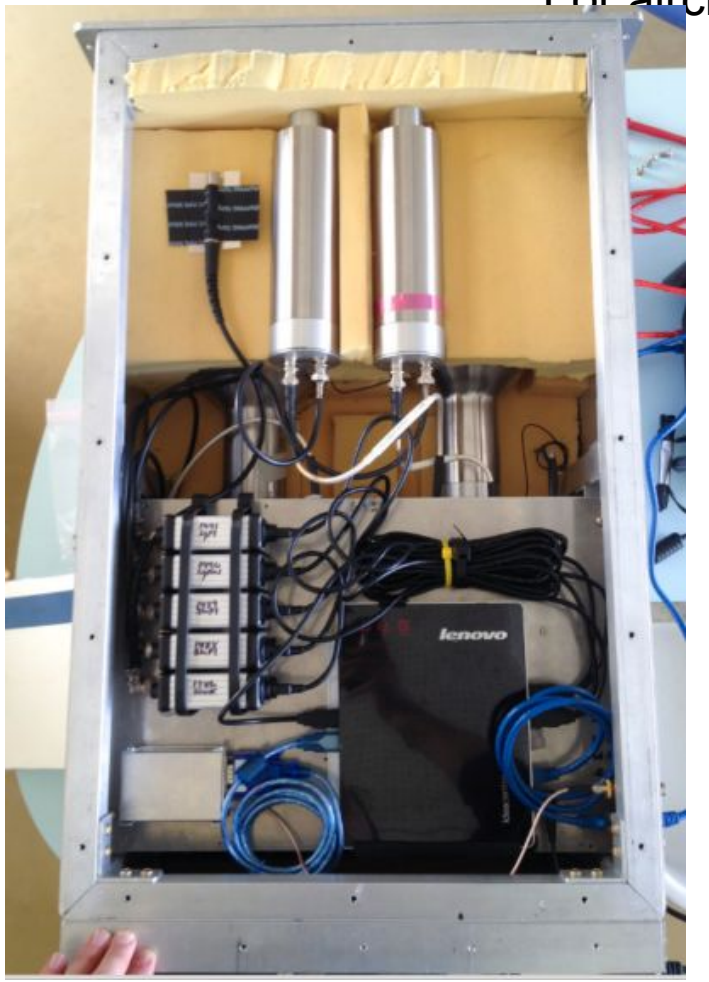

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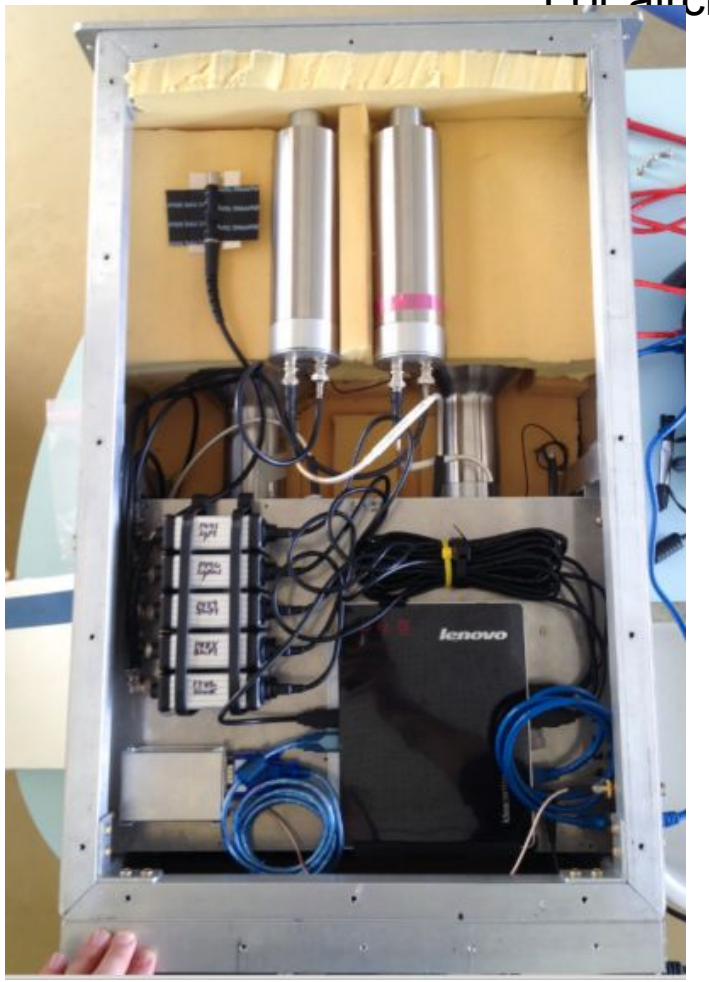

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- 12.5ns time resolution, 1 ms time precision
- Commercial electronics (Bridgeport Instruments)

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For aircraft and ground observations

THOR, 2021-present, Worldwide

Similar to GODOT but:

- 1us time precision (GPS)

Detector development at U.C. Santa Cruz, 2007-present

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Similar to GODOT but:

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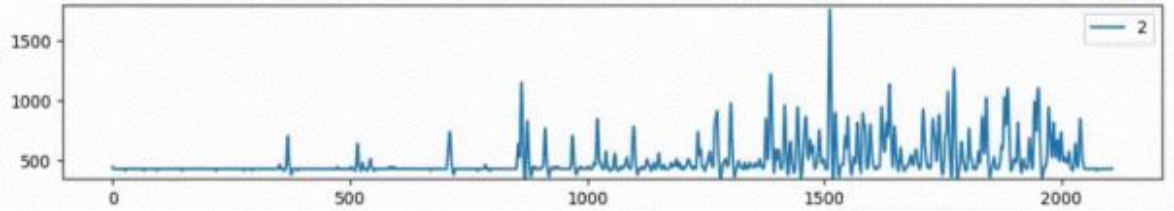

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For aircraft and ground observations

THOR, 2021-present, Worldwide

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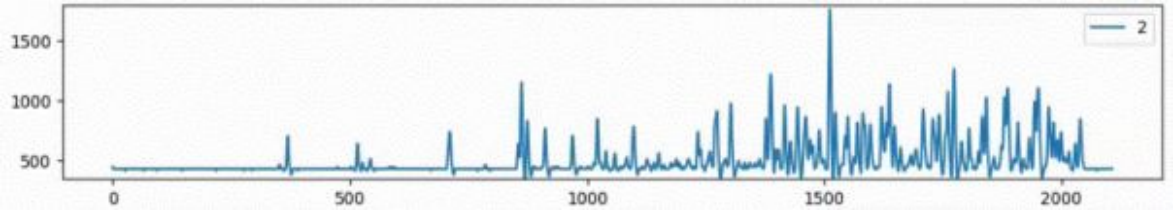
- 1us time precision (GPS)
- Triggered PMT trace mode
- 6 full copies (+ several smaller arrays)



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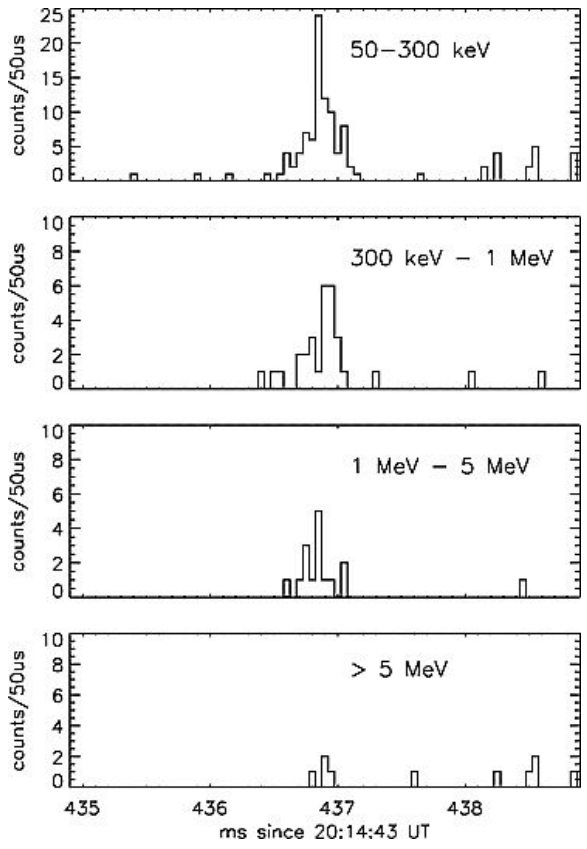
TGF science highlights from ADELE, GODOT, THOR

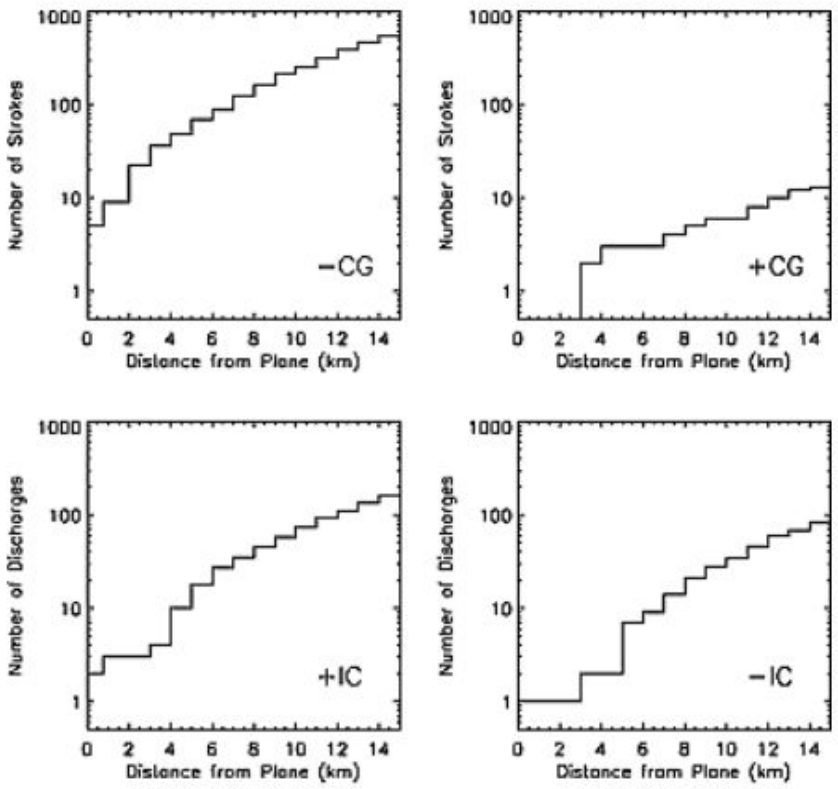
ADELE 2009 flights (NSF/NCAR Gulfstream V: Florida & nearby):



- First TGF observed from an aircraft

TGF science highlights from ADELE, GODOT, THOR

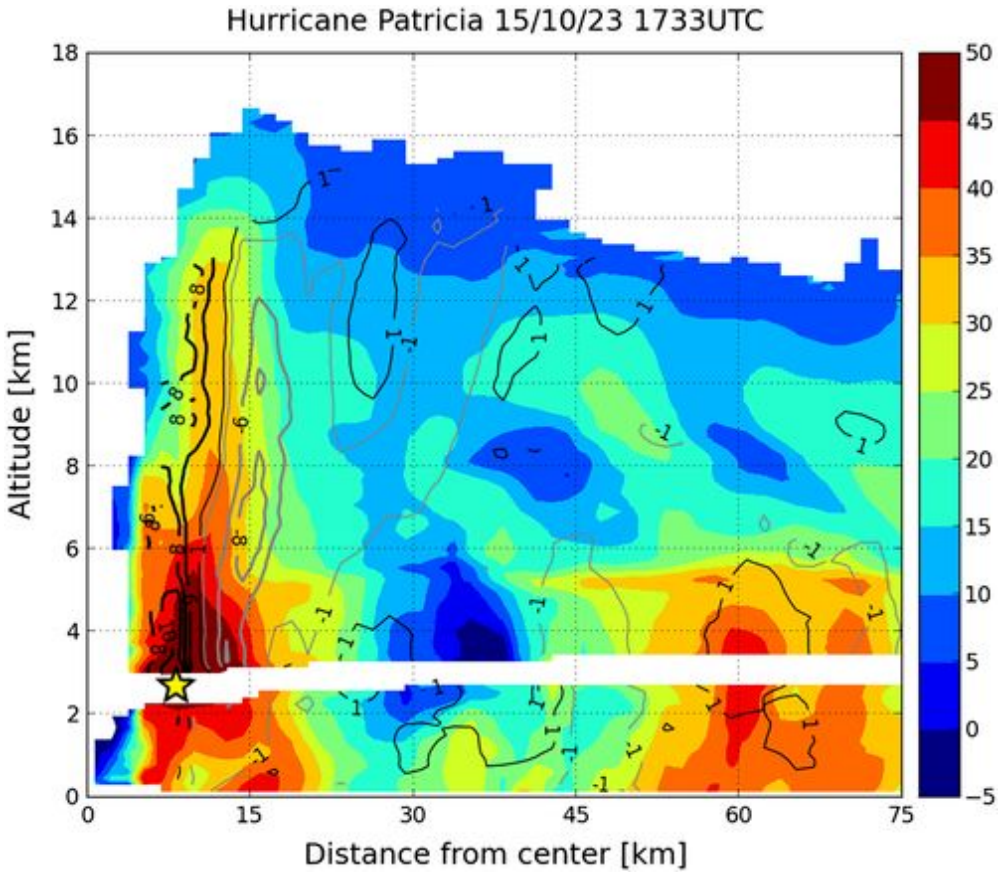
ADELE 2009 flights (NSF/NCAR Gulfstream V: Florida & nearby):



- Many much closer flashes with no TGF
- TGFs are rare
- TGFs are not necessary to trigger lightning

TGF science highlights from ADELE, GODOT, THOR

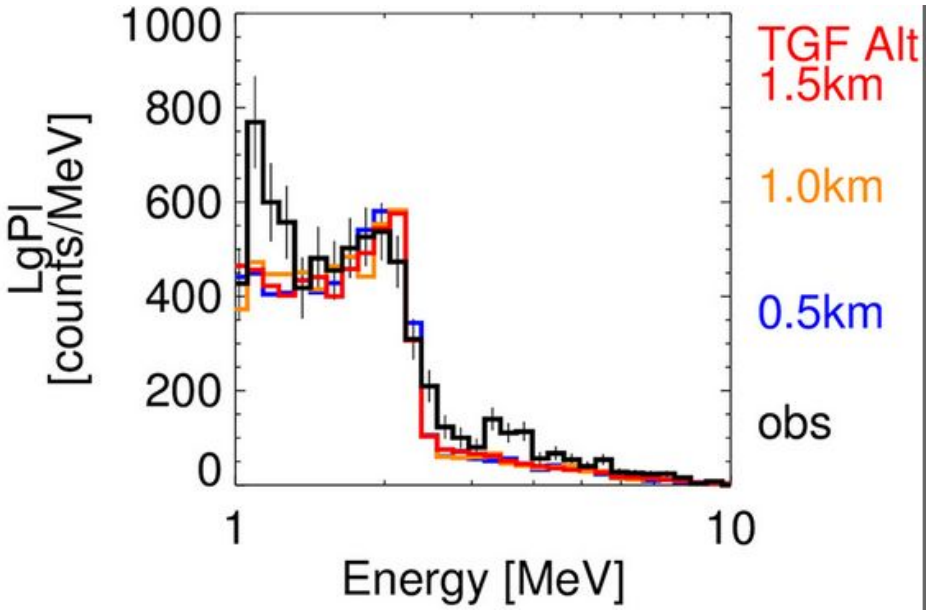
ADELE 2015 flights (NOAA WP-3D Orion):



- TGF in eyewall of Hurricane Patricia
- Upward TGF observed from below
- Implies reverse gamma-ray beam
  - generated by positrons

TGF science highlights from ADELE, GODOT, THOR

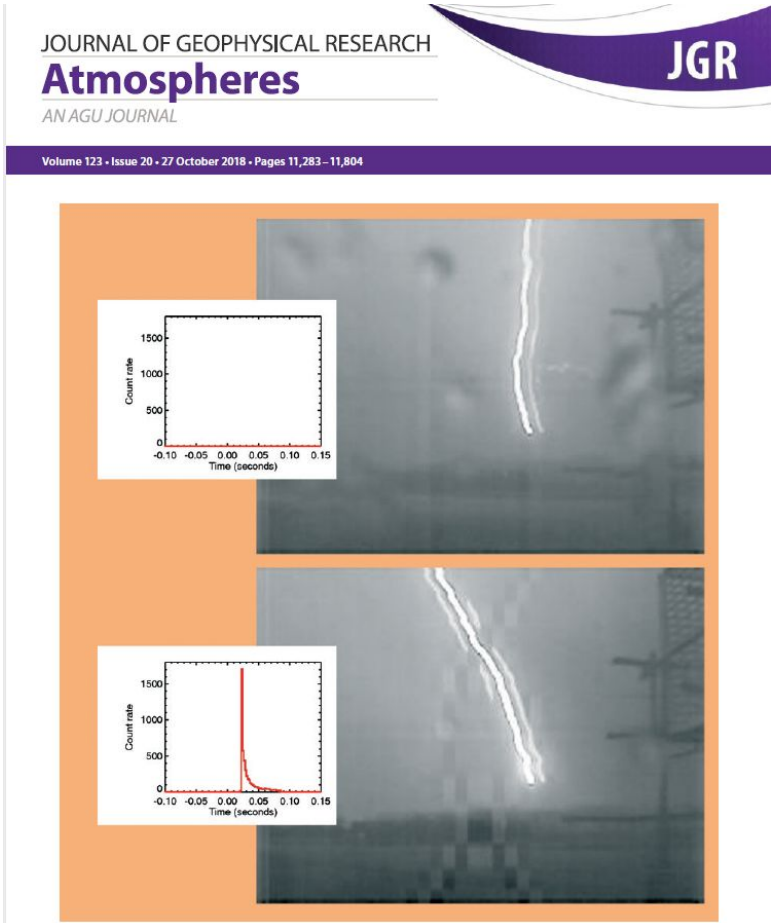
GODOT 2015 (On ground in winter, Uchinada, Japan):



- Spectral feature from neutron capture in plastic scintillator
- Consistent with simulations of a
- “standard” downward TGF
- Upward lightning from a tower

TGF science highlights from ADELE, GODOT, THOR

GODOT 2015 (On ground in winter, Uchinada, Japan):



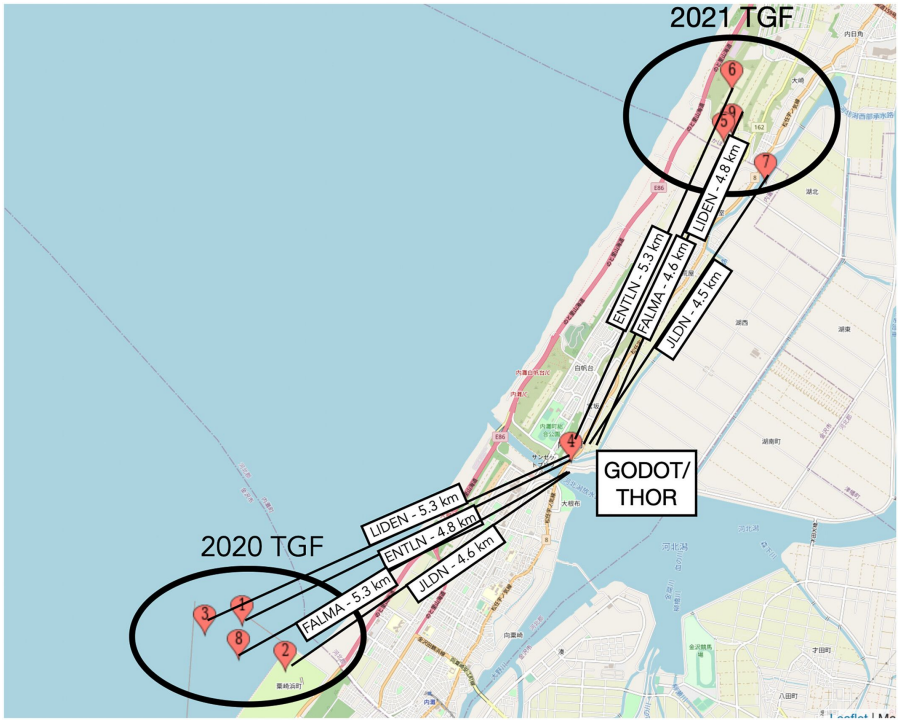
- Same flash (below) and another tower flash
- looked very similar, but the latter had no
- TGF

- Upper limit was 1/10,000,000 of the gammas
- implied by the neutron observation of the TGF

- TGFs “all or nothing”?

TGF science highlights from ADELE, GODOT, THOR

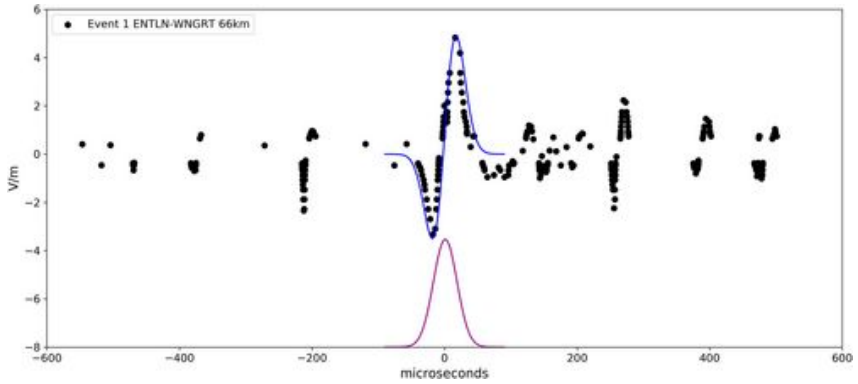
GODOT 2020/THOR 2021 (Uchinada, Japan):

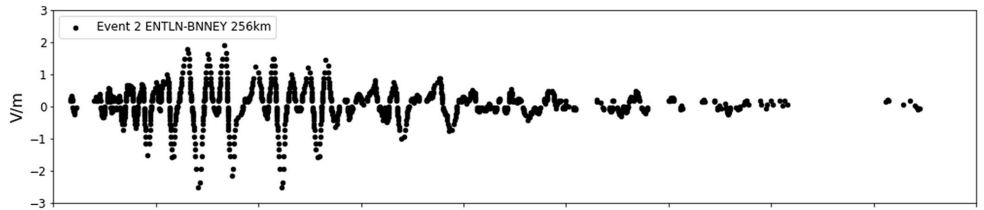


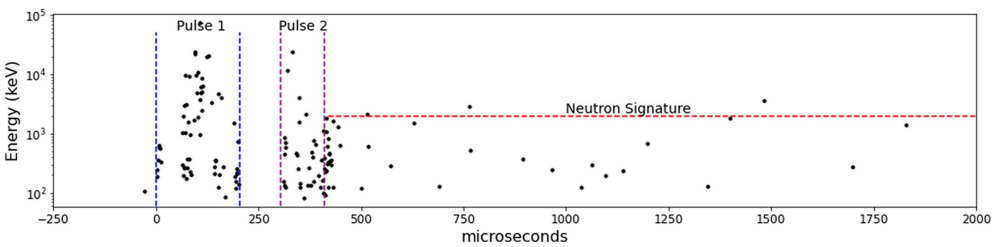
- Low altitude TGFs seen at ~5km distance
- Brighter than simulations expect
- Very bright? Horizontally beamed?
- Possibly consistent with Auger events

TGF science highlights from ADELE, GODOT, THOR

THOR 2022 (Mt. Santis, Switzerland):

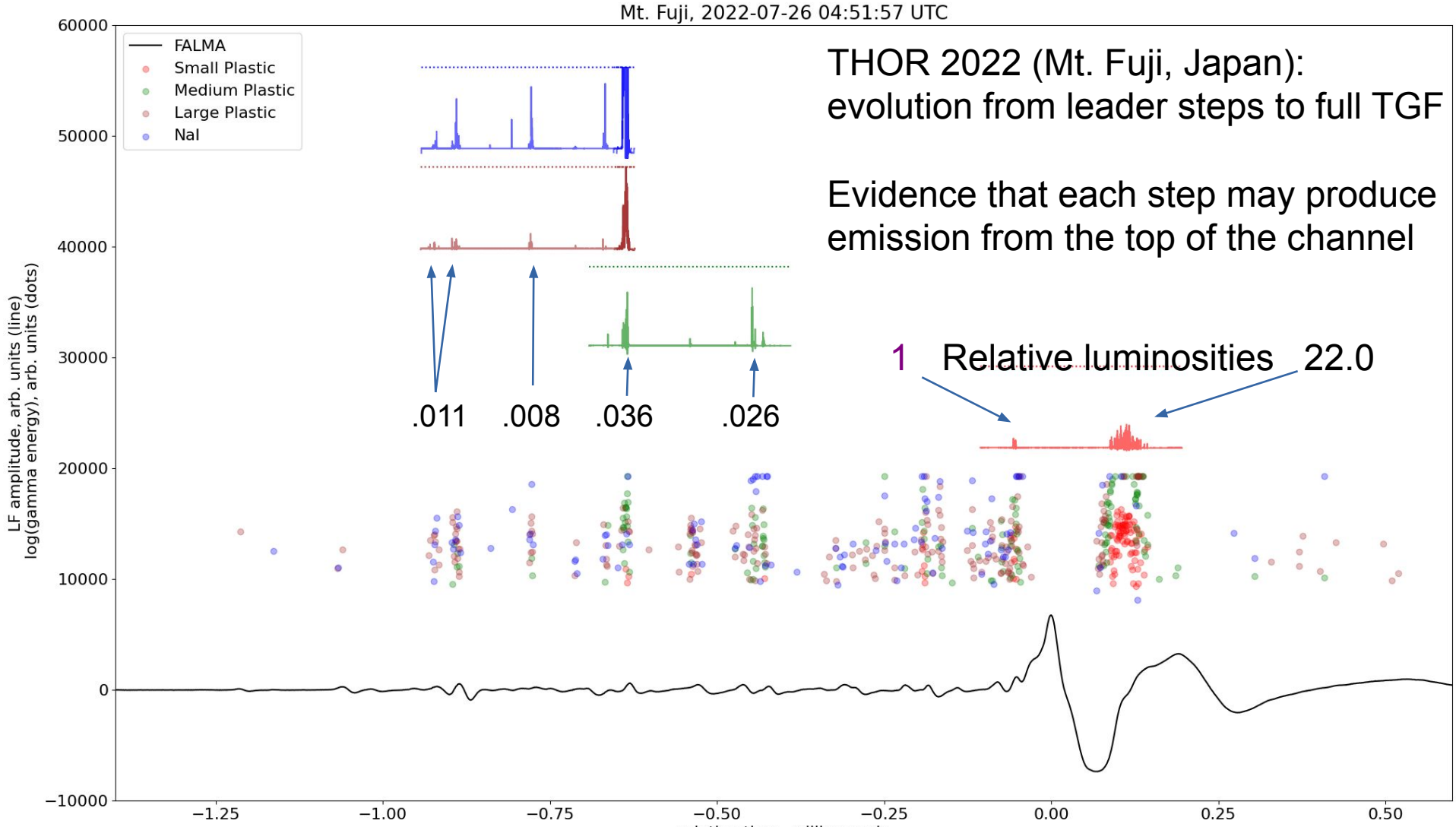






- First mountaintop TGFs
- Rare -IC TGFs
- One TGF occurred with the most
- energetic IC sferic of the year

TGF science highlights from ADELE, GODOT, THOR



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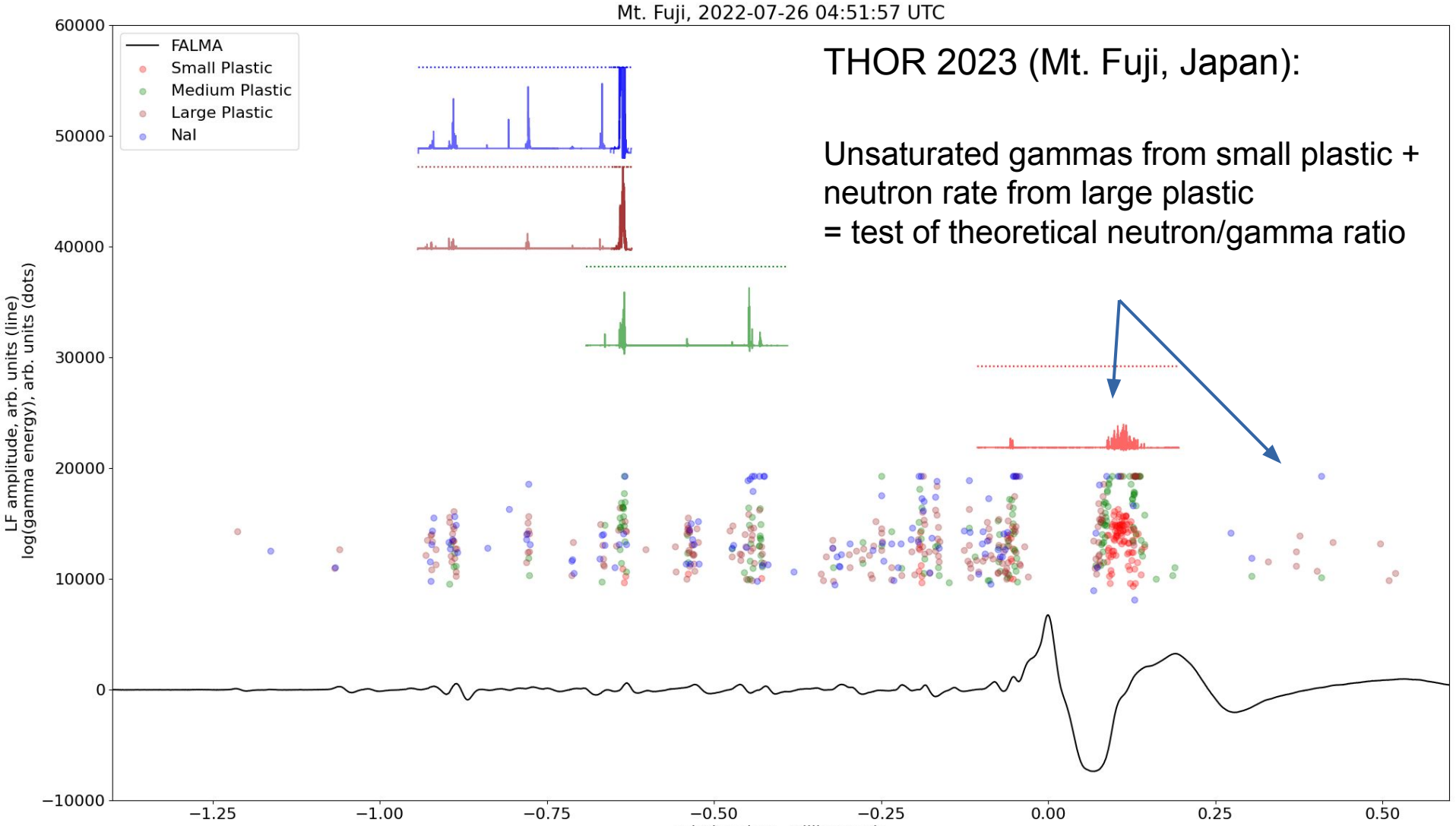

TGF science highlights from ADELE, GODOT, THOR

TGFs seen at:

Airborne:

Georgia coast
Gulf of Mexico

High altitude:

Mt. Fuji, Japan
Mt. Santis, Switzerland
Los Alamos, New Mexico, USA

Low altitude:

Uchinada, Japan
Split, Croatia

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Also: stepped-leader x-ray bursts

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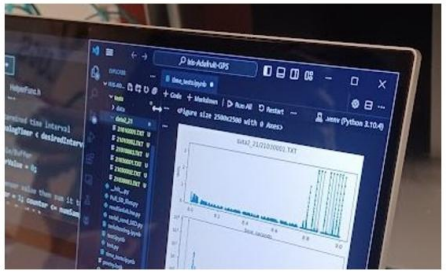
Intense Radiation Integration Sensor (IRIS)

Inexpensive, insensitive detector based on commercial photodiodes

First IRIS prototypes, tested at MD Anderson Cancer Center, Houston, 9/23



IRIS first light, MD Anderson

IRIS testing team. Left to right:
Michelle Pichardo, Sophia Urizar (undergrad);
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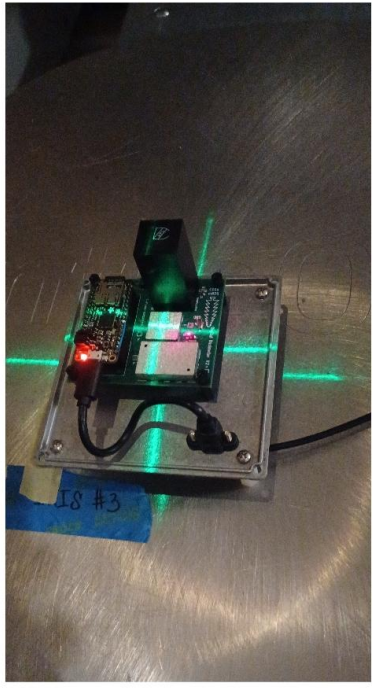

IRIS unit with cover off, being aligned with the accelerator beam center.

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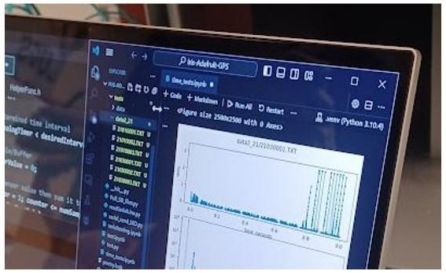

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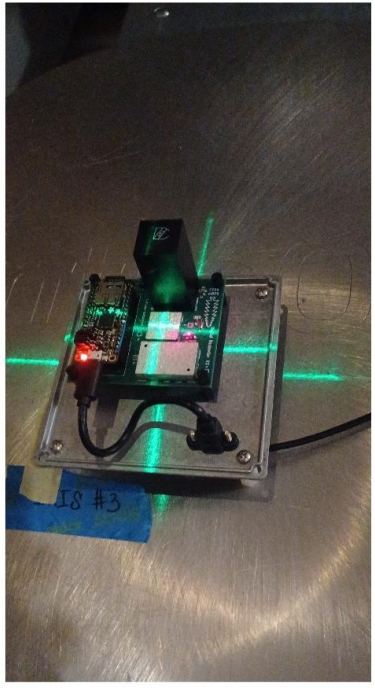

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Extend's THOR's dynamic range by about 5 orders of magnitude

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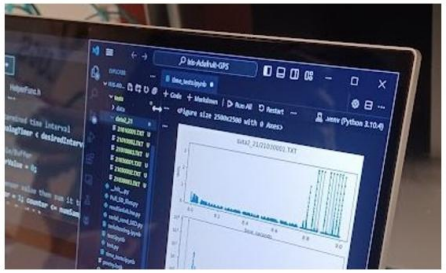

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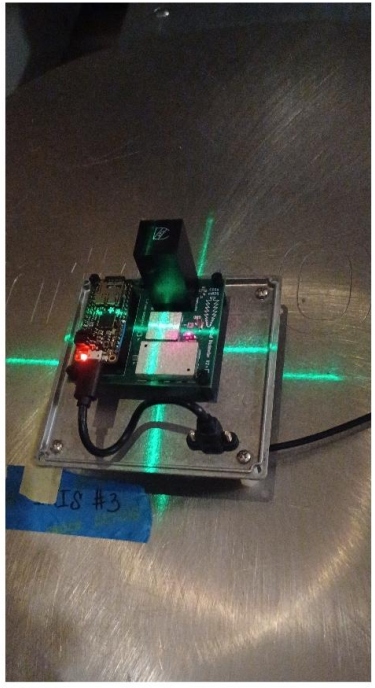

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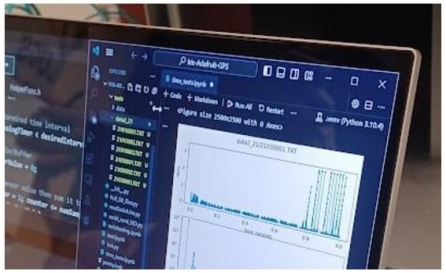

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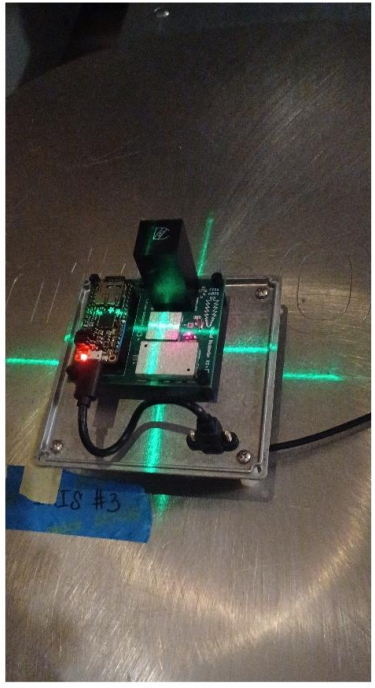

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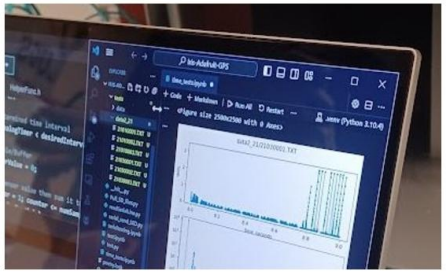

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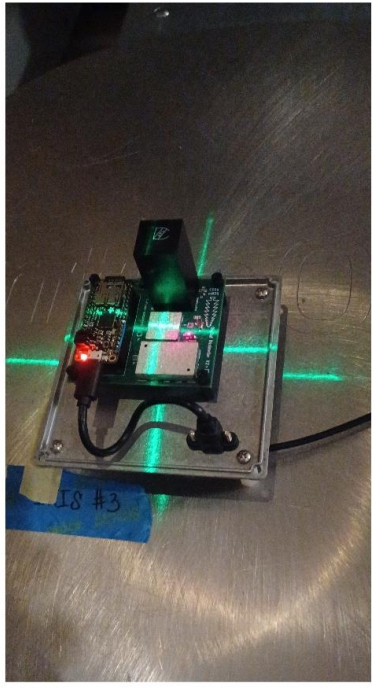

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Should be available for loan to research sites next year