100 years of quantum physics

High-Speed Camera Spectroscopy in Lightning Research

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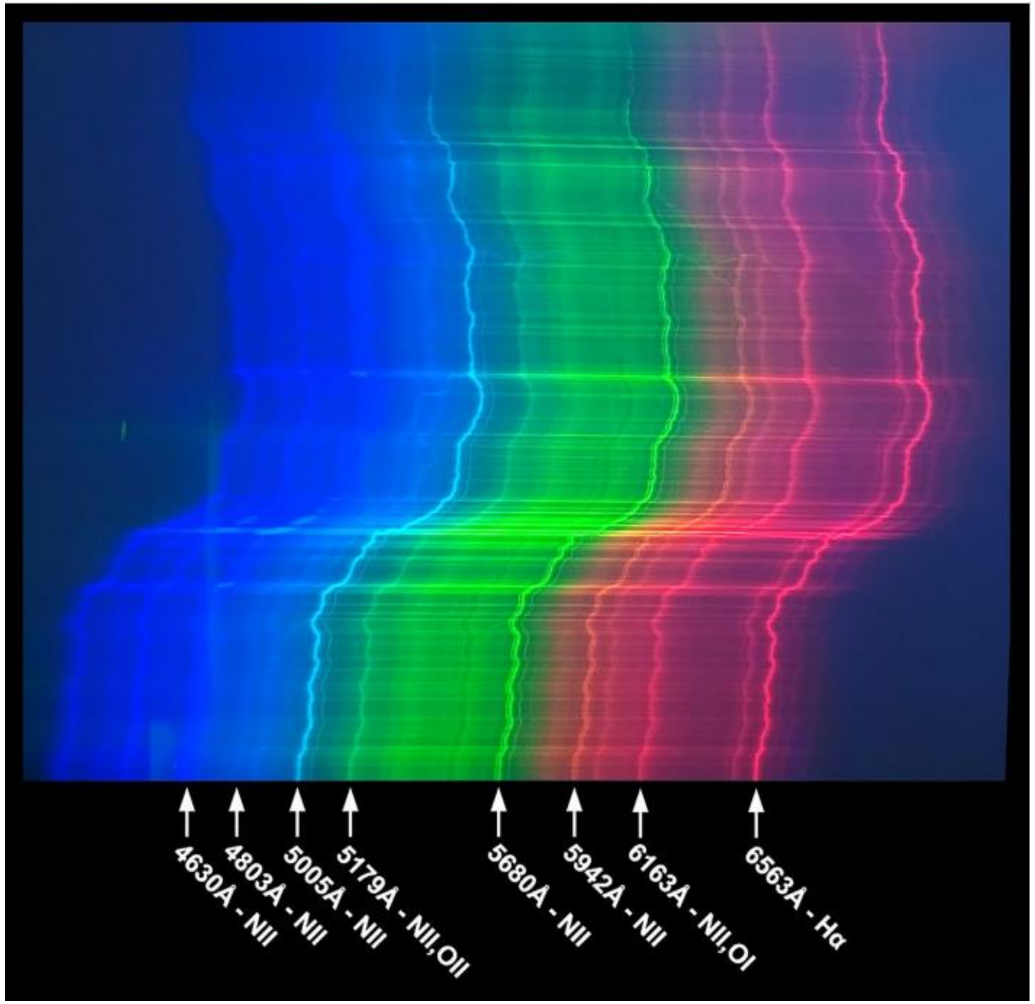


Visible spectrum of a negative cloud-to-ground flash.
Captured using a Nikon D700 camera.
Image courtesy of co-author Tom Warner.

Introduction

- 2012: **XVIII VIETNAM SCHOOL OF PHYSICS (VSOP-18)**
  Quy Nhon, 23 July - 4 August 2012

  RENCONTRES DU VIETNAM

- 2015 – 2017: Physics of Space, Atomics and Molecules Interactions

  Master thesis: **Plasma spectroscopy**

- 2017 – 2021: Ph.D thesis : **Lightning spectroscopy**

- 2021 - 2025: Postdoc: **Lightning** and its related phenomena (**TGFs**)

1. Lightning

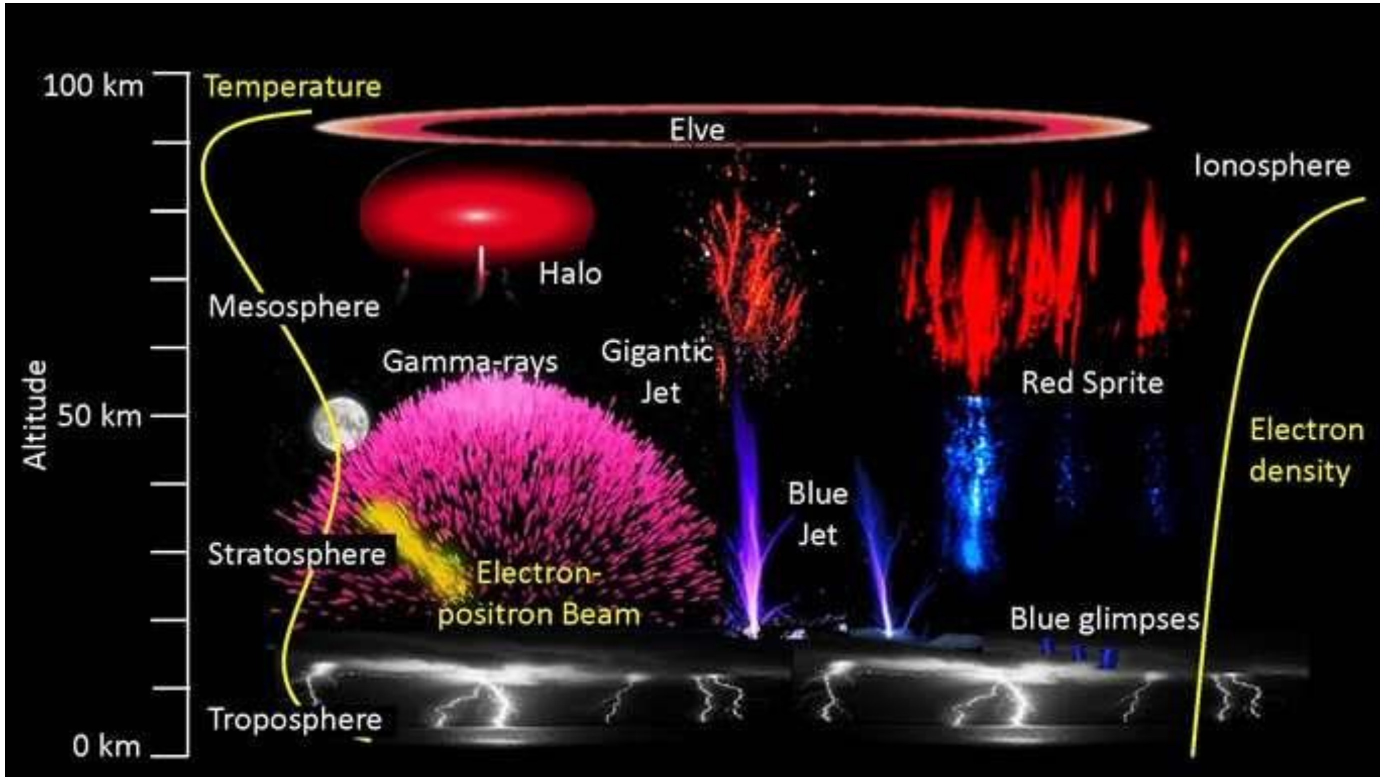
- **Common phenomenon**

1.4 billion (10^9)
flashes/year
44 ± 5 flashes/second
(Christian et al., 2003).

https://www.youtube.com/watch?v=3P-vD01vvJs

1. How is lightning initiated ?

1. Lightning



- **Transient Luminous Events (TLEs)** such as red Sprites, halos, blue starters, blue jets, gigantic jets and Elves.

- **Terrestrial Gamma Ray Flashes (TGFs)**

2. Lightning related phenomena are not yet well understood

2. Lightning spectroscopy

Leader

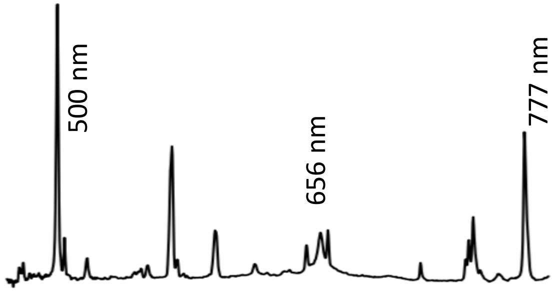
1st Return stroke

After return stroke

A high-speed camera

A lightning **flash** ≡ many lightning **strokes**

Spectrograph



- Chemical signature
- Determination of:
  - T
  - Ne
  - P, …

2. Lightning spectroscopy

1961

315 – 980 nm

Time-averaged

Wallace

Atoms: N II, N I, O I,

Molecules: CN, N_2, N_2^+

1962

385 – 690 nm 17.5 ms

Time-resolved/flash

Salanave

Atoms: N II, N I, O I,

Molecules: CN, N_2, N_2^+

Te & Ne quantify

1968

400 – 660 nm

2 – 5 µs

Time-resolved/stroke

Orville et al.

Atoms: N II, N I, O I, O II

Dynamics Te and Ne

No molecules.

2017

380 – 620 nm

620 – 870 nm

1.5 µs

Time-resolved/phases

Walker et al.

Doubly ionized: N III

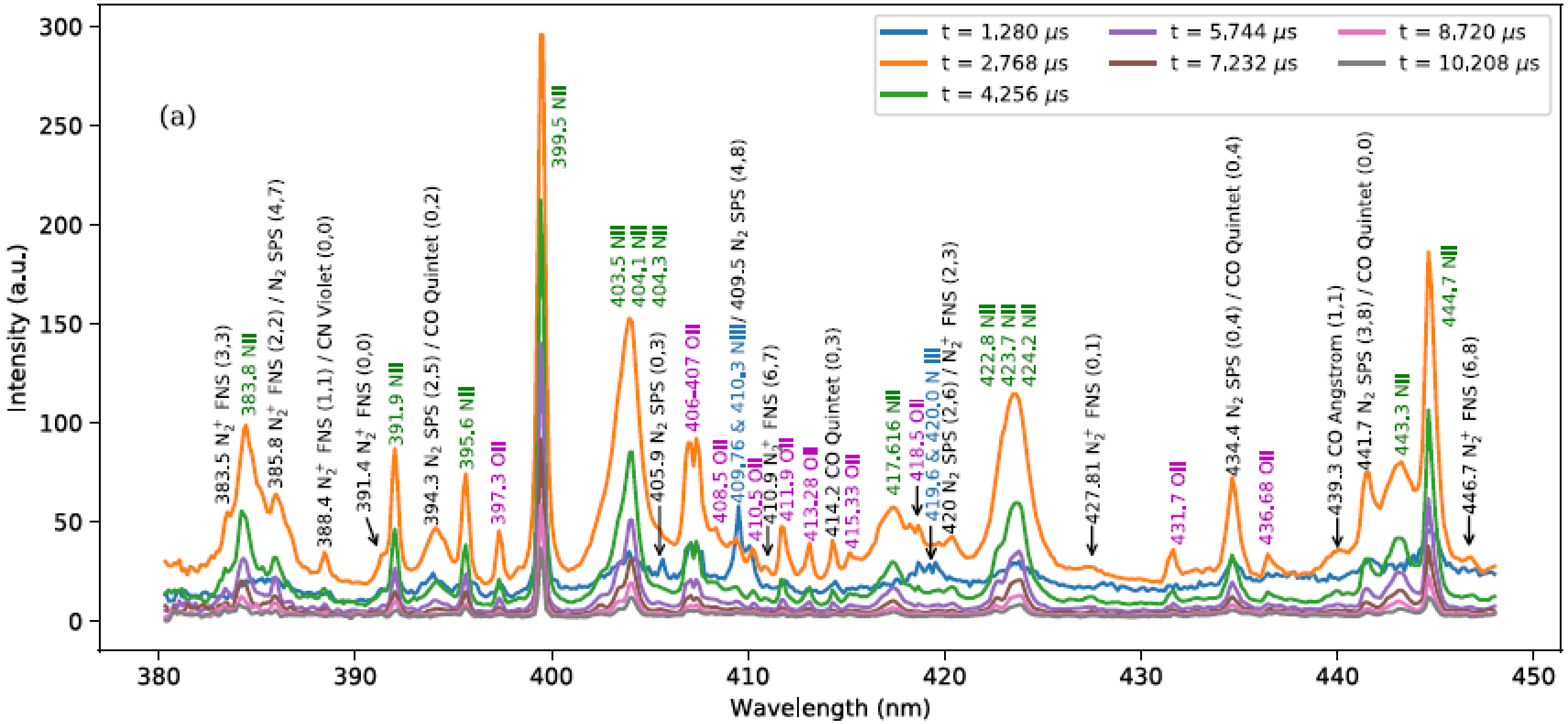
Atoms: N II, N I, O I, O II

High Te and Ne

No molecules

3. Lightning spectroscopy → Return stroke

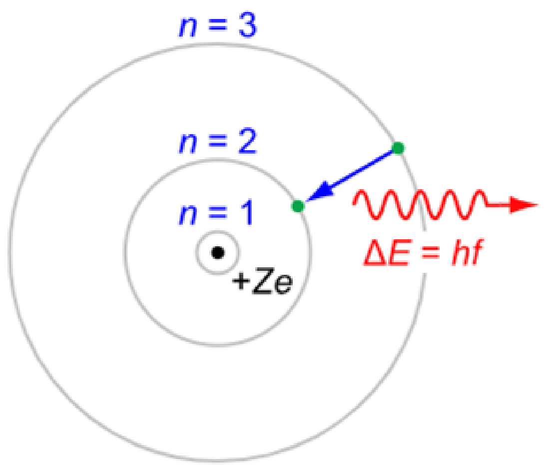
(a) Chemincal identification



Time resolved spectra of a laboratory discharge (Kieu et al., 2021)

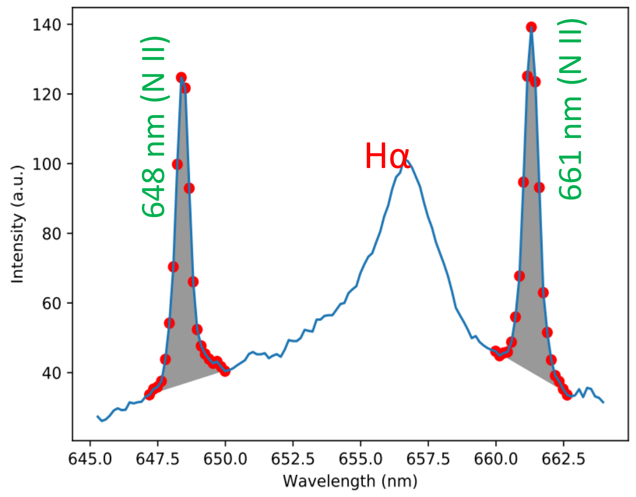
3. Lightning spectroscopy → Return stroke

(b) Temperature estimation



$$\boxed{\mathrm{T} = \frac{\epsilon_m - \epsilon_n}{k\ln(I_{nr}g_m A_{mp}\nu_{mp}/I_{mp}g_n A_{nr}\nu_{nr})}}$$

- $\varepsilon_m, \varepsilon_n$ is the excitation energy (eV)
- g_m, g_n is the statistical weight
- A_{mp}, A_{nr} is the Einstein emission coefficient (s^{-1})
- $\vartheta_{mp}, \vartheta_{nr}$ is the frequency (cm^{-1})



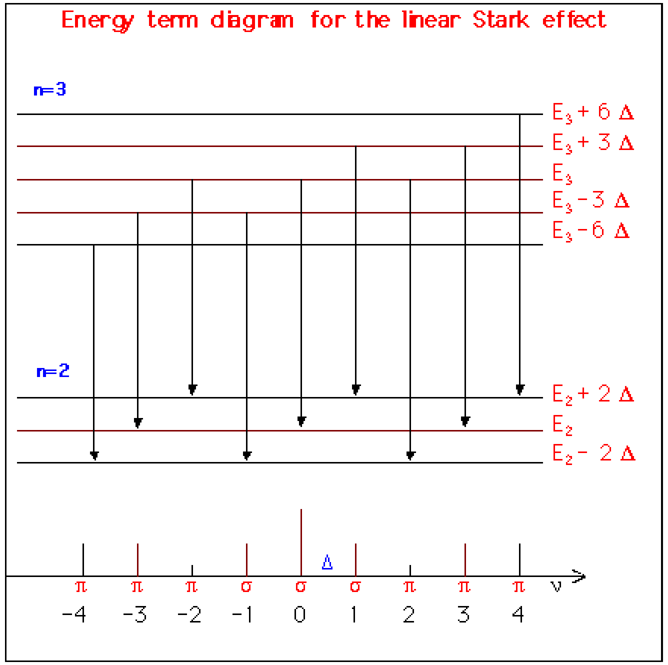
- Errors:

$$\frac{\delta T}{T} = \frac{1}{ln(Rg_m\nu_{mp}A_{mp}/g_n\nu_{nr}A_{nr})}[(\frac{\delta R}{R})^2 + (\frac{\delta A_{mp}}{A_{mp}})^2 + (\frac{\delta A_{nr}}{A_{nr}})^2]^{1/2}$$

3. Lightning spectroscopy → Return stroke

(c) Electron density

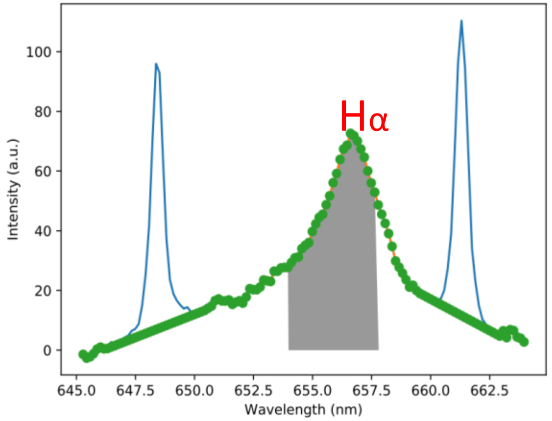
derived from the **full width half area (FWHA)** of the H alpha emission:



Stark Effect

$$N_e = 10^{17} \times \left(\frac{FWHA}{1.098}\right)^{1.47135} cm^{-3}.$$

(Gigosos et al., 2003)

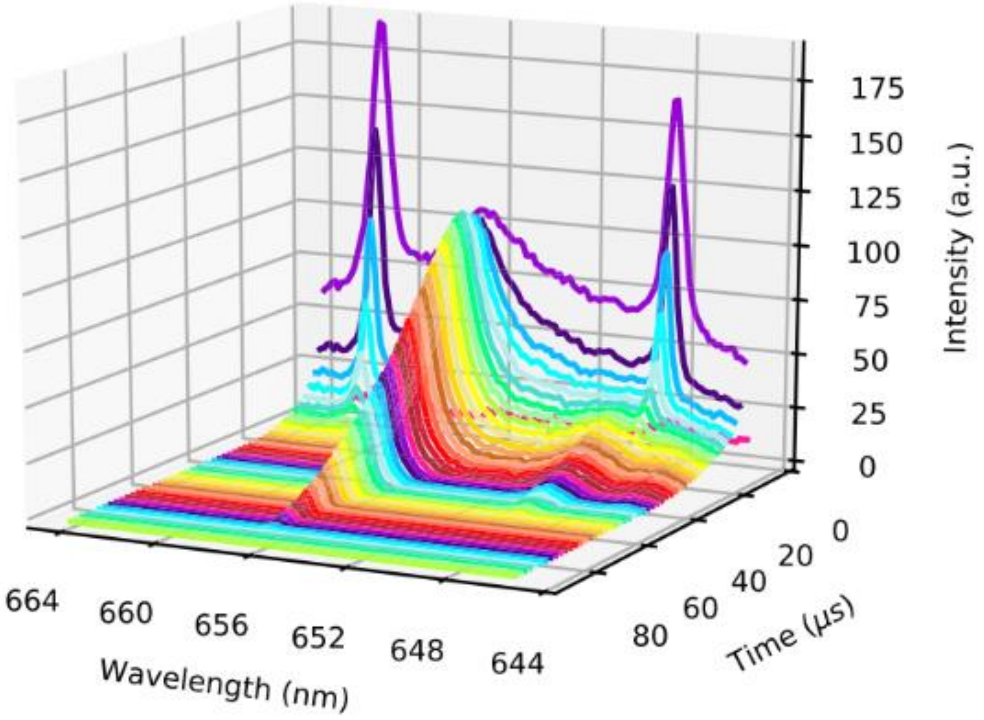


- Errors: Bootstrap method

Subsampling the data with replacement (i.e., if we have N data points, we select among them N points allowing for repetition)

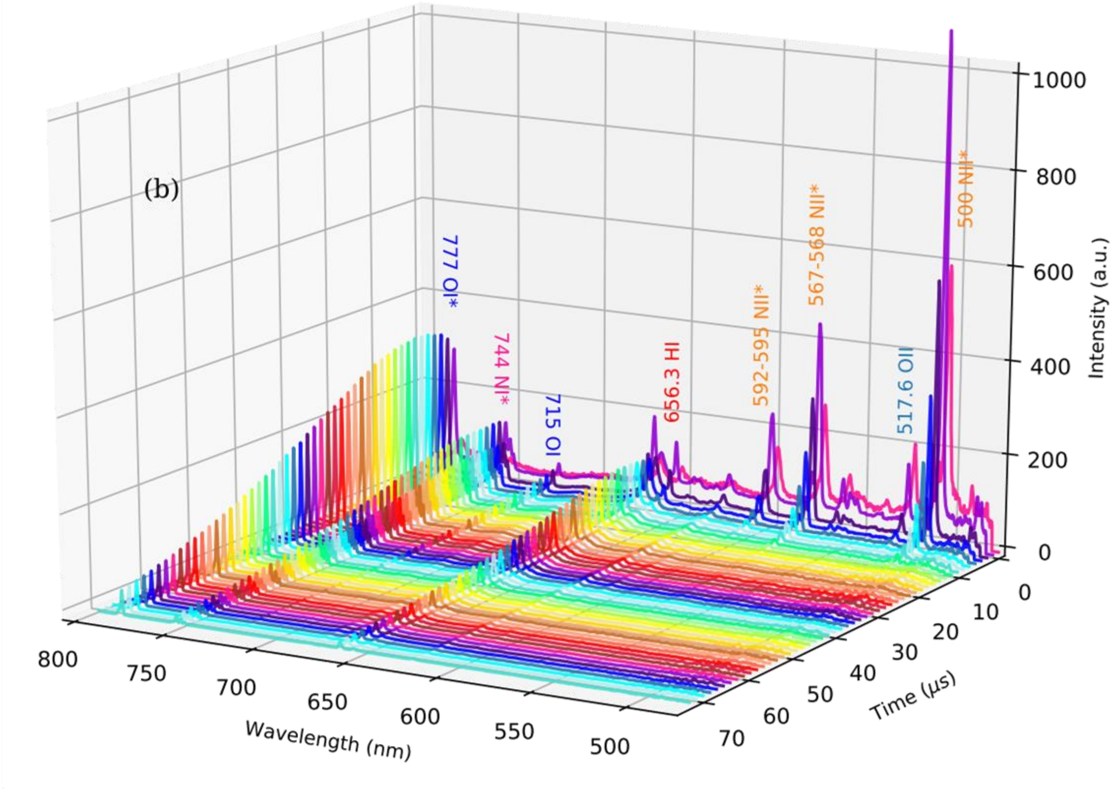
3. Lightning spectroscopy → Laboratory like-lightning discharges

2.1 Mfp



0.5 µs

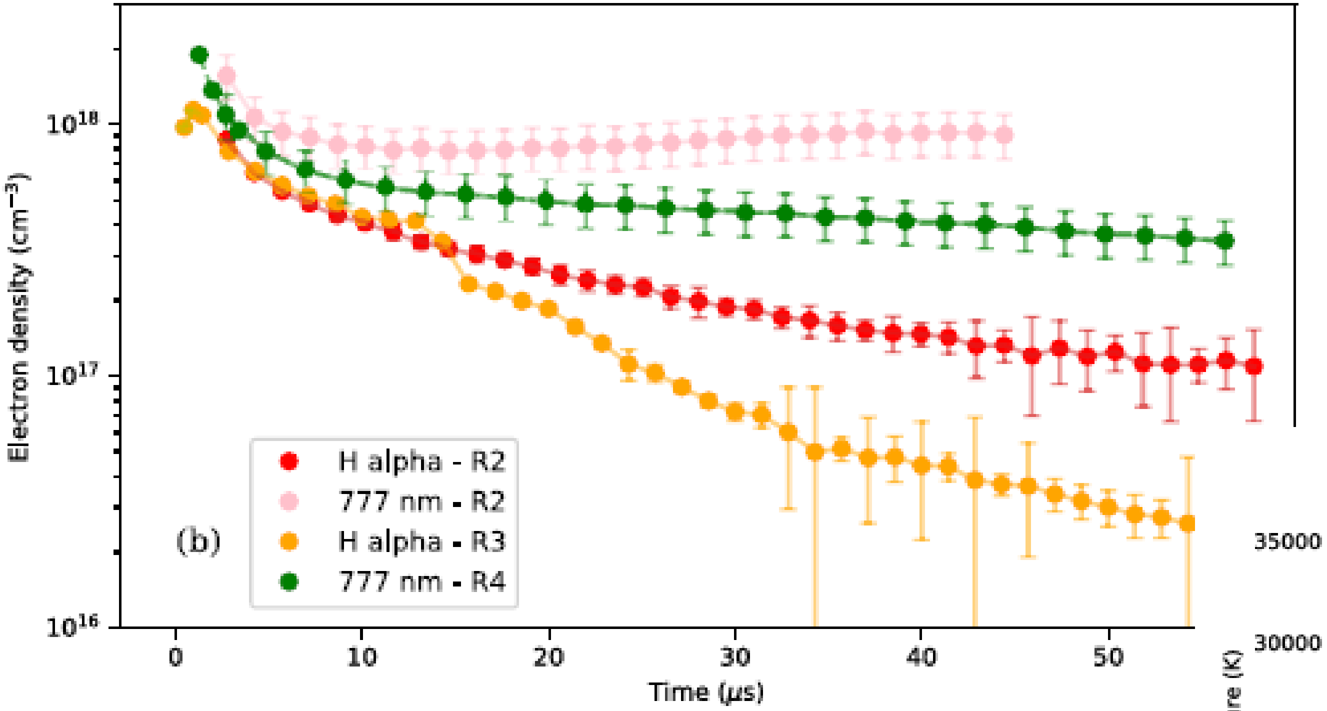
670 kfp



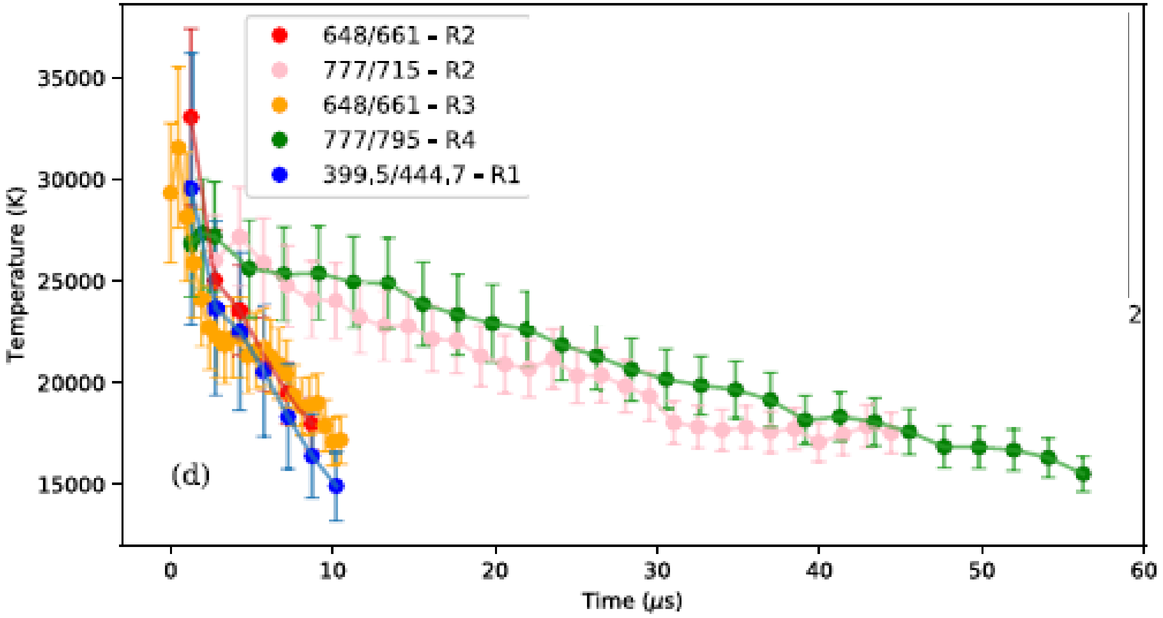
1.5 µs

Dynamics of the time resolved spectra of a laboratory discharge (Kieu et al., 2020, 2021)

3. Lightning spectroscopy → Laboratory like-lightning discharges



(Kieu et al., 2021)

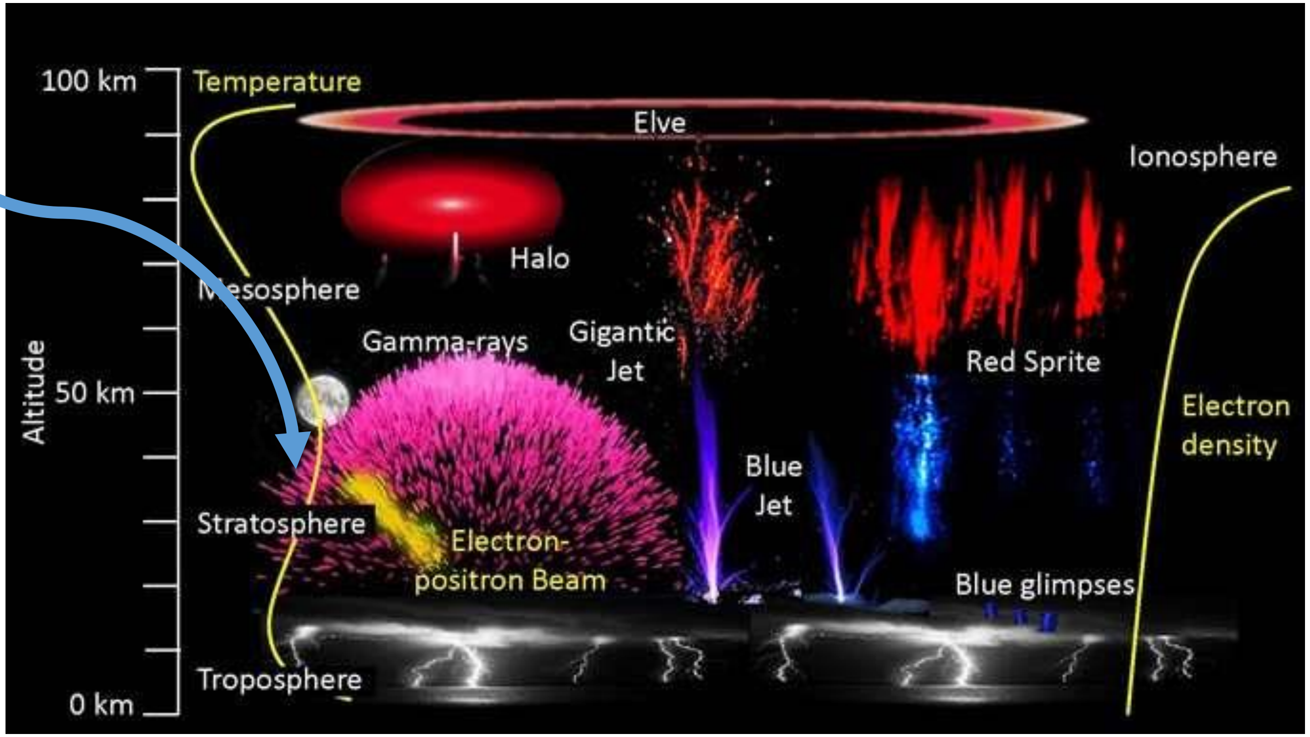


670 kfps, 1.5 µs

4. Lightning spectroscopy → lightning related phenomena

Terrestrial Gamma-ray flashes (TGFs) are **energetic** Gamma bursts.

- First discover from space in 1994
- Photon Energy: from **10** to **100 MeV** or more
- For each TGF, the source must produce 10^{18} photon at the source
- Mechanism: Relativistic Runaway Electron Avalanches (RREAs)



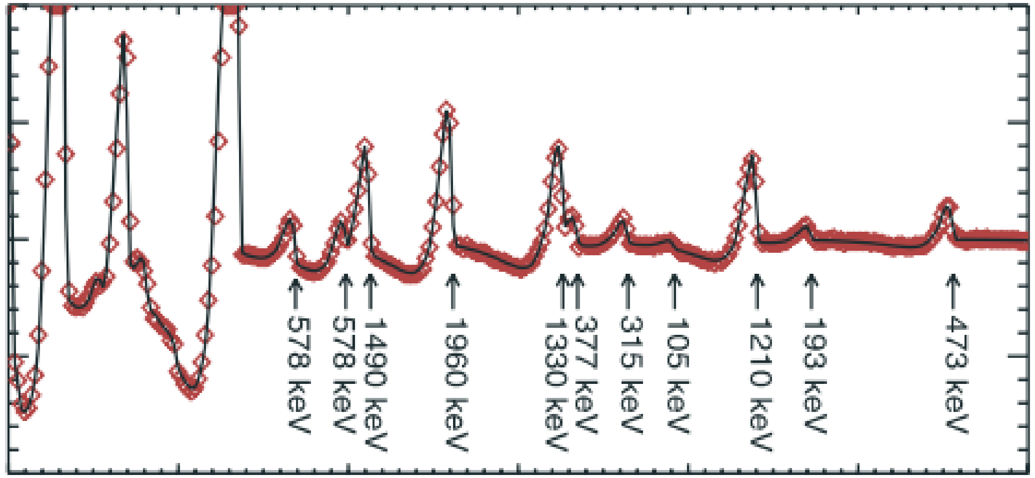
Lightning and its related phenomena

4. Lightning spectroscopy → lightning related phenomena

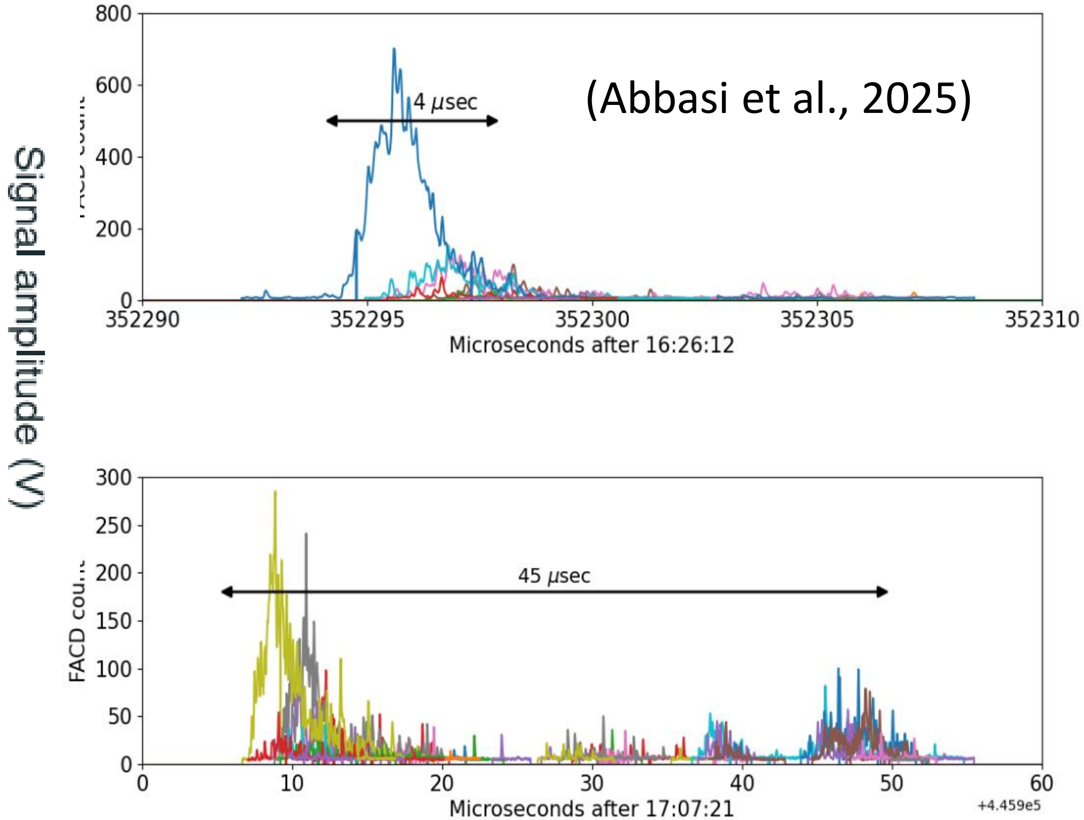
Terrestrial Gamma-ray flashes (TGFs) are **energetic** Gamma bursts.

> 1 MeV, duration > 1 us

X-ray or gamma-ray emissions



(Dwyer et al., 2004)



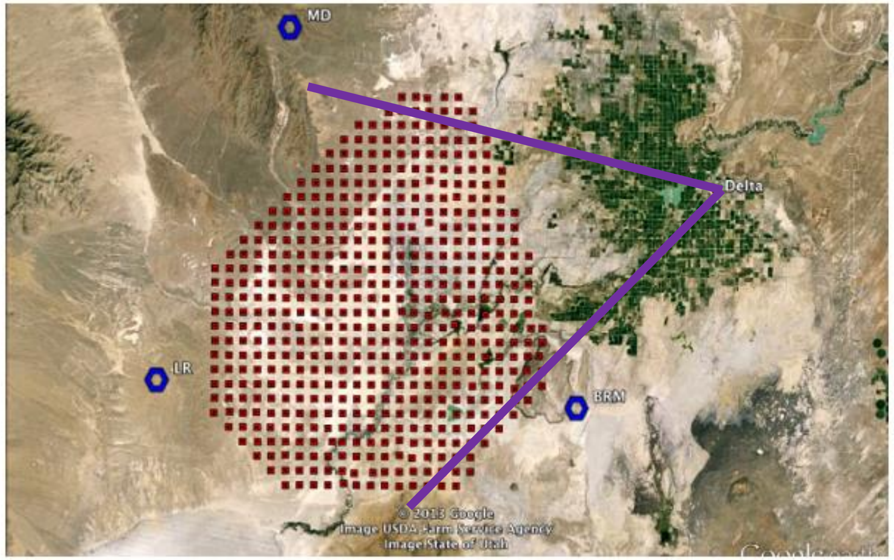
- Photon Energy: from **10 to 100 MeV** or more

The most energetic radiation in the Earth's atmosphere

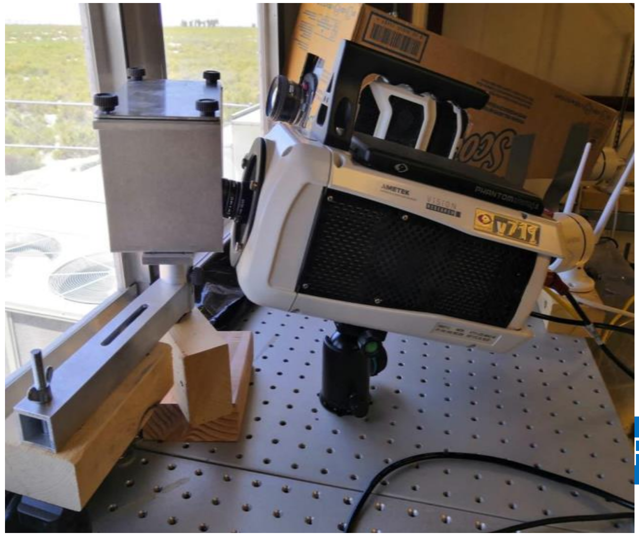
4. Lightning spectroscopy → lightning related phenomena

Telescope Array Surface Detectors (**TASDs**) is located just to the west of Delta, Utah, USA.

It primarily designed to detect ultra-high energy cosmic rays, **, includes 507 detectors, covering an area of 700** $\mathbf{km^2}$,.



a) The layout of our facilities



b) The spectroscopic system

FA

c) A high speed camera

4. Lightning spectroscopy → lightning related phenomena

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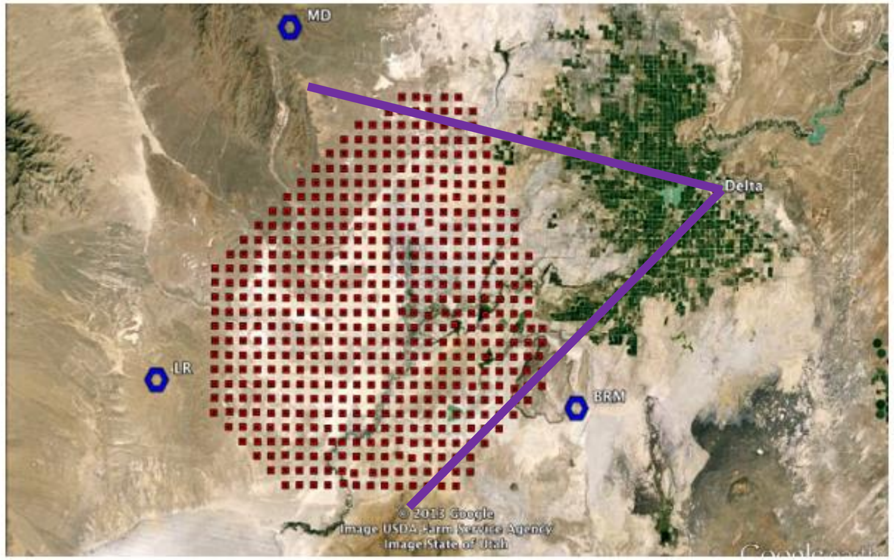
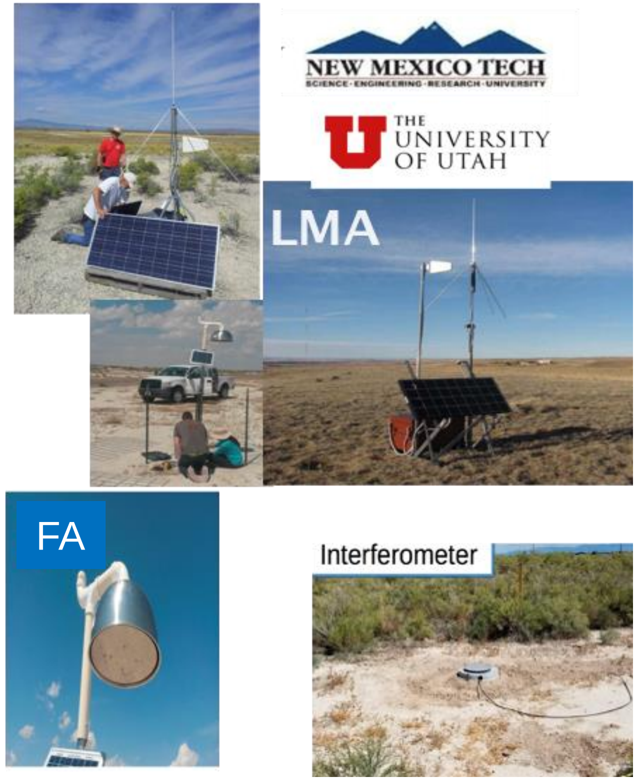


a) The layout of our facilities

Surface detector



d) Other lightning detectors

4. Lightning spectroscopy → lightning related phenomena

On September 11th, 2021, the high-speed camera recorded optical components **during the leader phase** of 6 downward TGFs at the TASD site.

https://www.youtube.com/watch?v=gn08IO69iGA

Leaders without TGF production

40 kfps

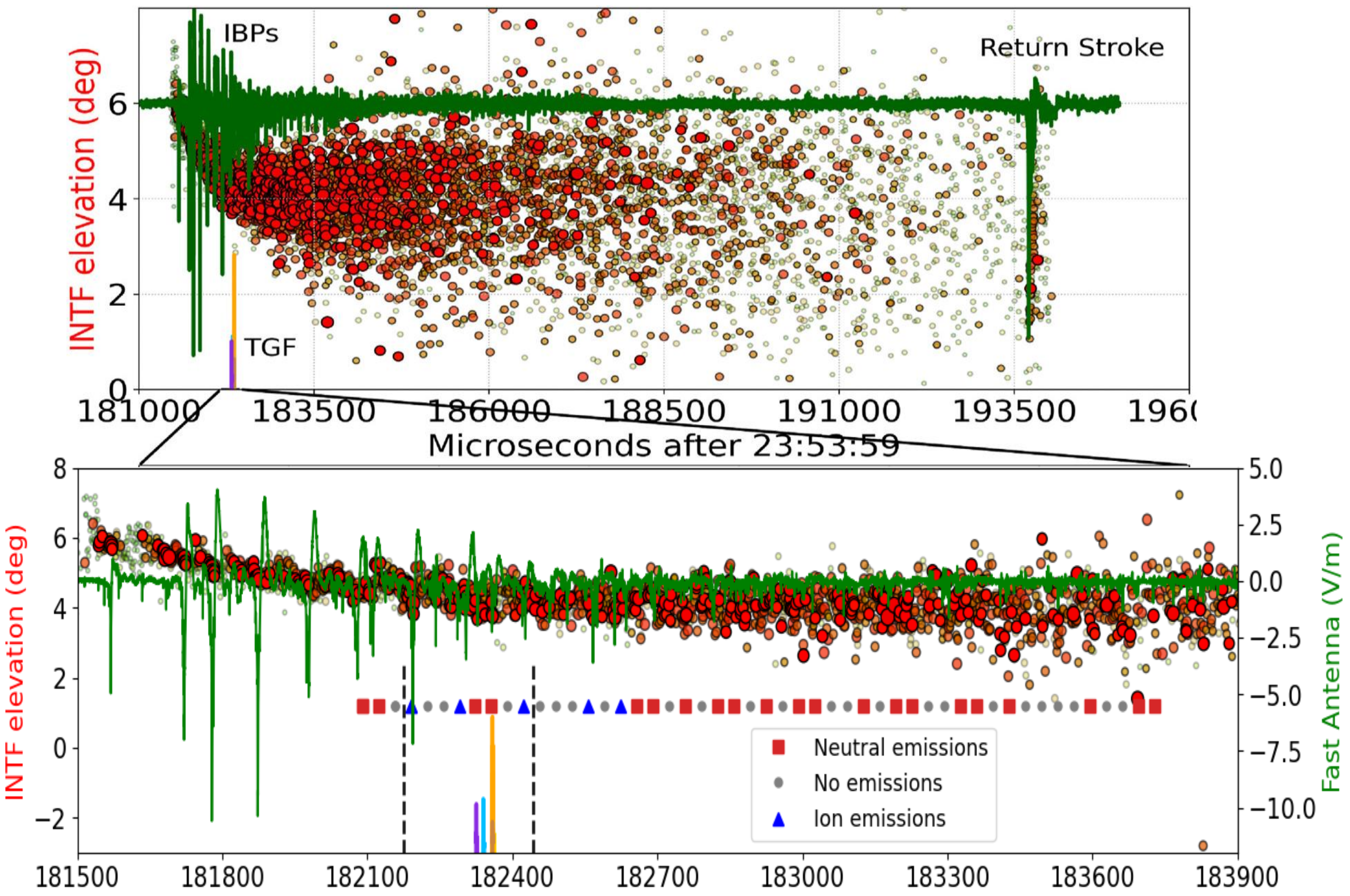
25 µs

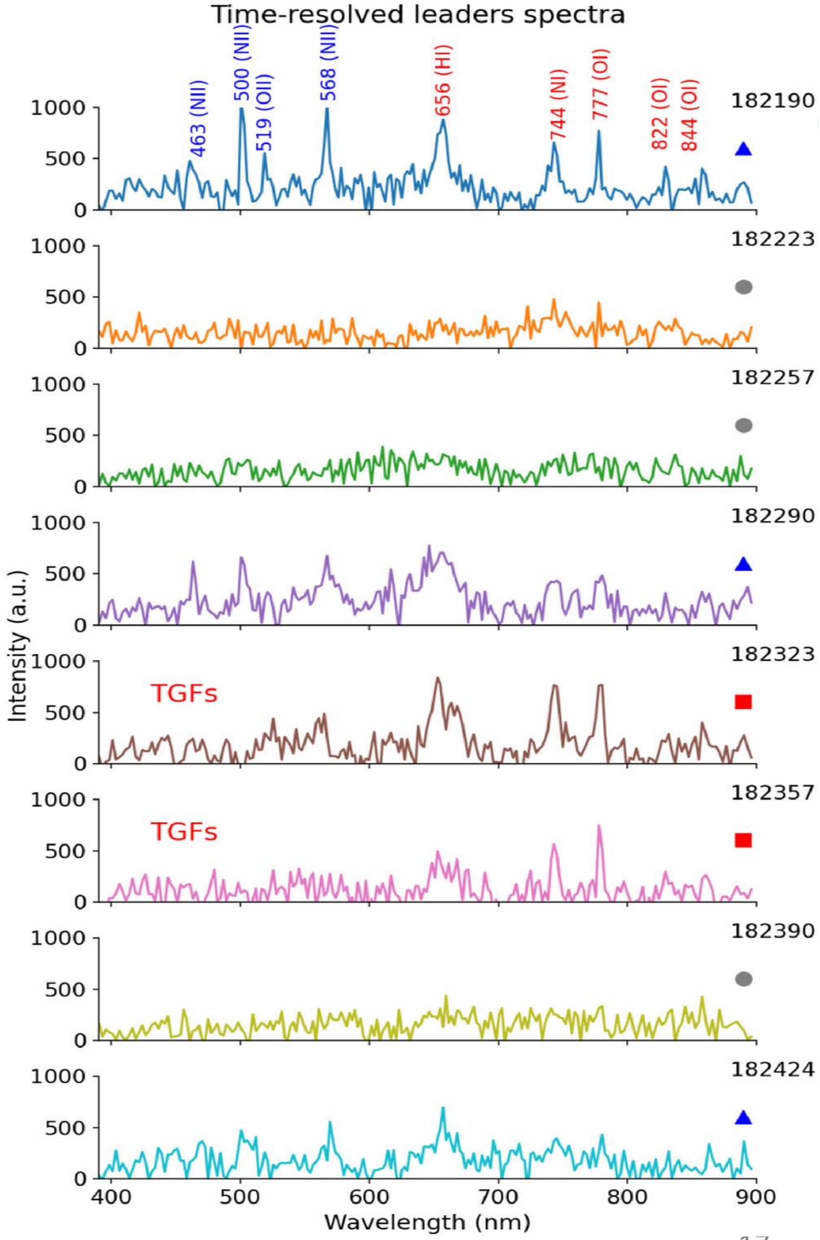
https://www.youtube.com/watch?v=lNAHilAsFLo
(Abbasi et al., 2025)

4. Lightning spectroscopy → lightning re

(Kieu et al., 2024

First leader spectra associated with TGF detections





Summary

Spectroscopy is a powerful tool in lightning research

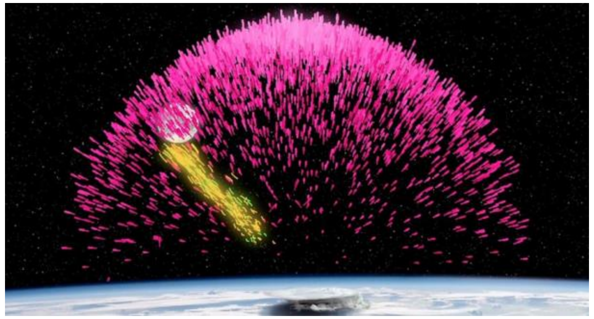
- **For lightning return strokes:**
    - chemical identification
    - physical quantification (e.g., temperature, electron density, pressure, conductivity).
- **For related phenomena (e.g., TGFs):**
    - optical emissions

Leader

Return stroke

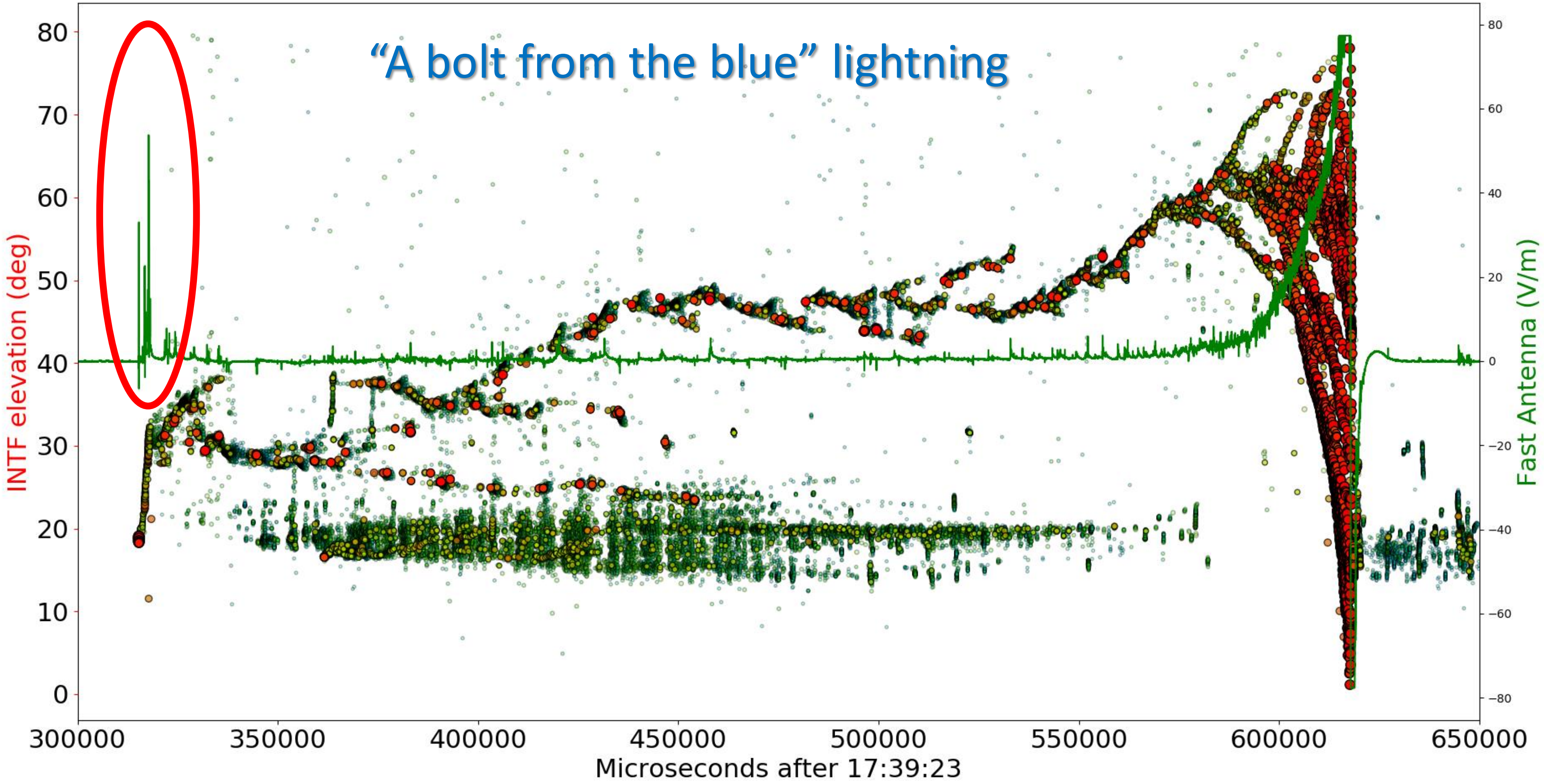
Spectrograph

TGFs

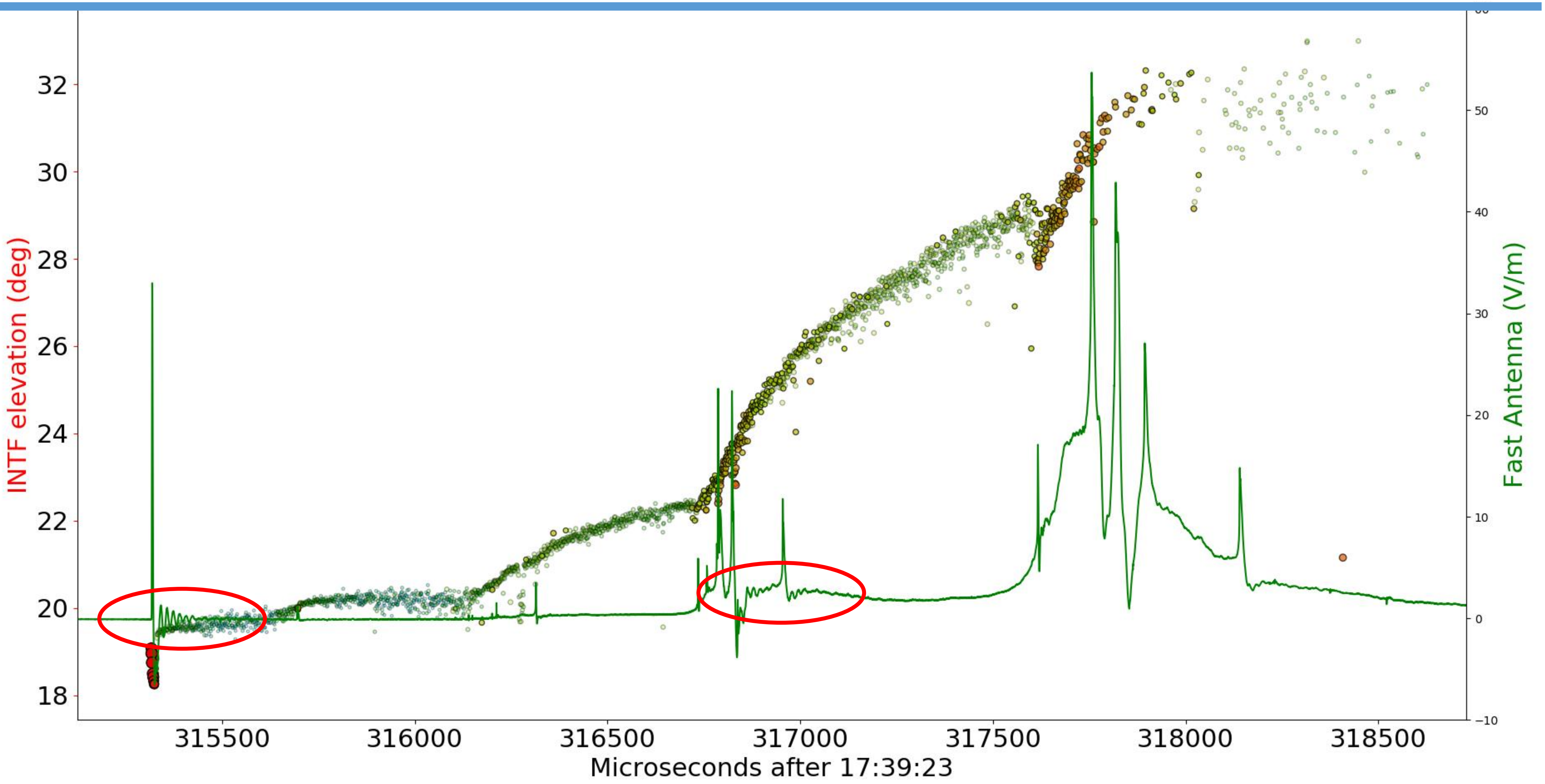


5. Lightning initiation

September 11, 2021 at the TASD



5. Lightning initiation



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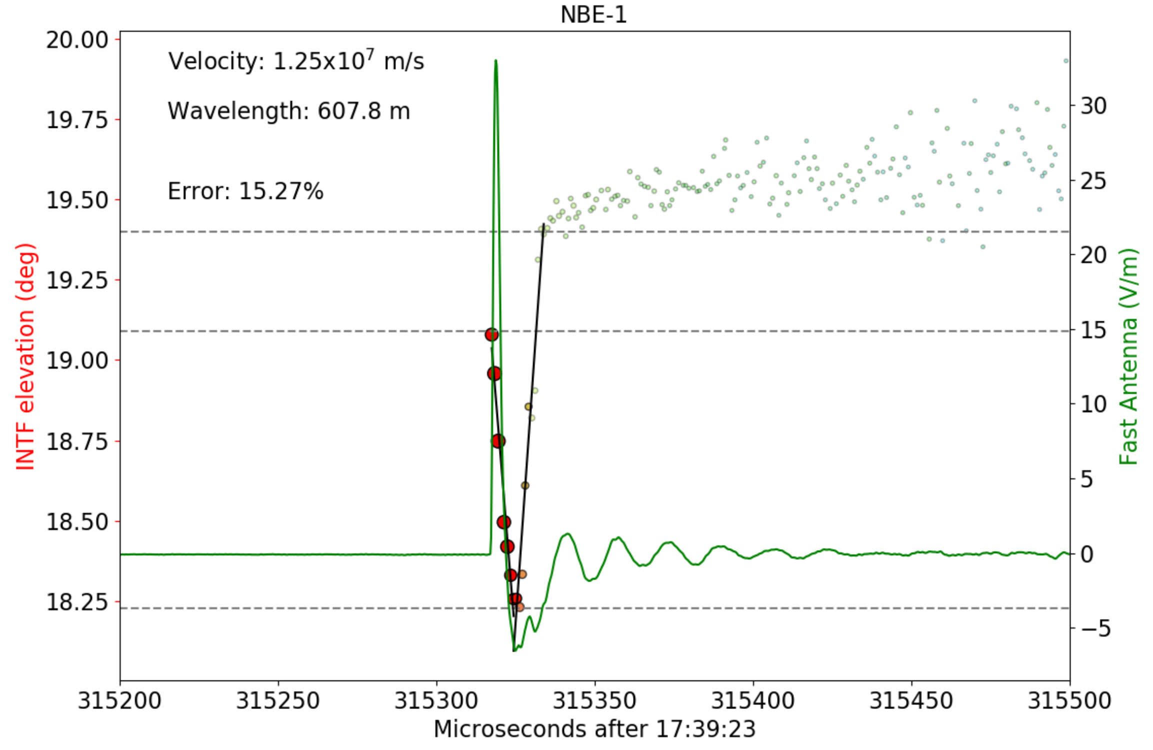
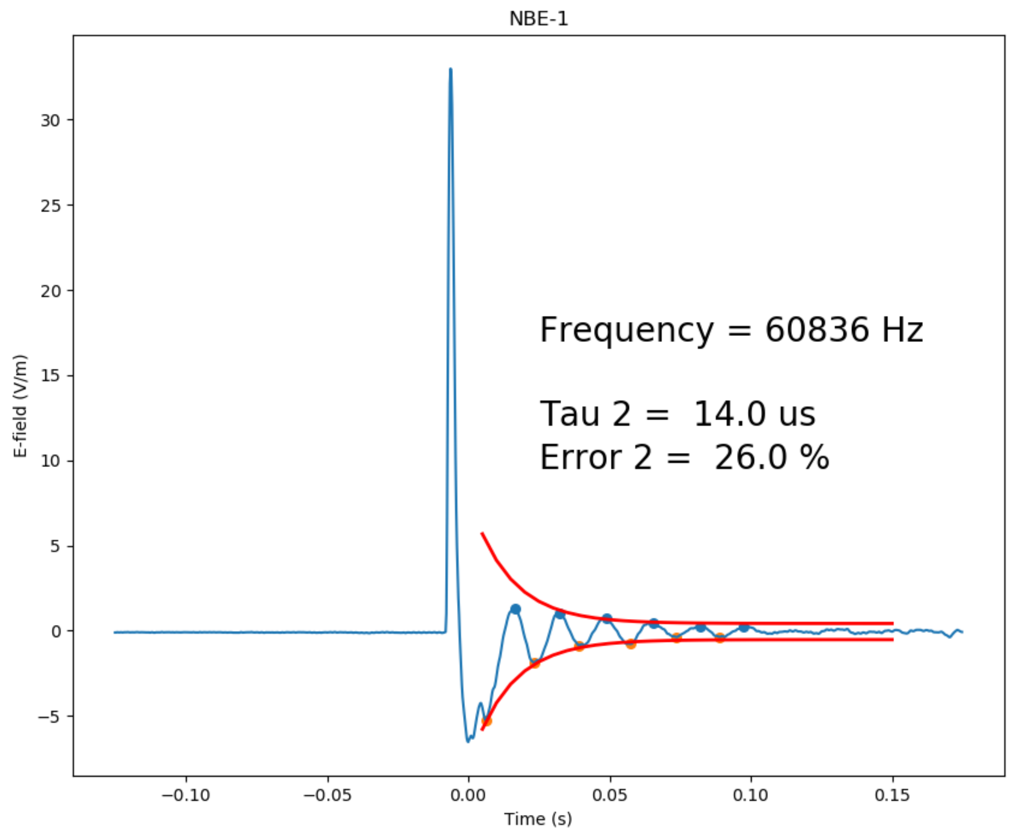




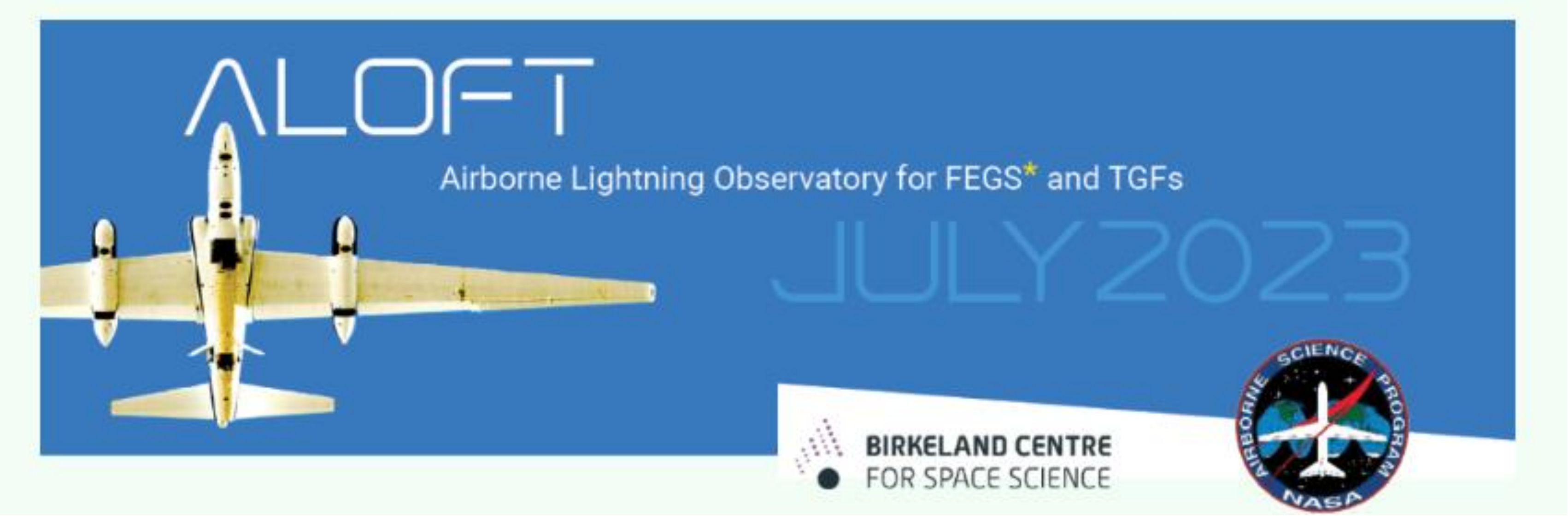
NBE - 1

Damped oscillations

6. Spaced-base observation

ALOFT was a collaboration between NASA and the University of Bergen that flew the ER-2 aircraft over tropical thunderstorms

- TGF production mechanism
- The relationship between TGFs and gamma glow



https://www.nature.com/articles/s41586-024-07936-6

https://www.nature.com/articles/s41586-024-07893-0

https://www.nature.com/articles/d41586-024-03032-x

6. Spaced-base observation

NASA nghiên cứu tia gamm

laodong.vn/cong-nghe/nasa-nghien-cuu-tia-gamma-sieu-nang-luong-bang-may-bay-cam-tu-1231342.ldo

LAO ĐỘNG

CƠ QUAN CỦA TỔNG LIÊN ĐOÀN LAO ĐỘNG VIỆT NAM

DU LỊCH CÔNG ĐOÀN Dân tộc

Mặt trận Xã hội Thế giới Media Thời sự Pháp luật Kinh doanh Công đoàn Bạn đọc ... 59s Trắc nghiệm

CÔNG NGHỆ

Thế giới số - Vũ khí - Quân sự

NASA nghiên cứu tia gamma siêu năng lượng bằng "máy bay cảm tử"

ANH VŨ - Thứ hai, 21/08/2023 11:05 (GMT+7)

Theo dõi Báo Lao Động trên Google News

NASA vừa tiến hành một nghiên cứu đầy thách thức, sử dụng chiếc máy bay do thám U-2 đã được sửa đổi để bay thẳng vào mây giông nhằm nghiên cứu tia gamma siêu năng lượng.

Acknowledgement

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Aix*Marseille université Socialement engagée

Quantum physics → Lightning physics

Thank You!