Lightning and TLEs observed from the ISS during the Ax-4 space mission

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1. Introduction

The crew of Axiom Space's Ax-4 mission spent 19 days on the International Space Station from 26 June to 14 July, 2025. **The UHU experiment** (uhu.epss.hu/en), part of the mission's scientific payloads, aimed to observe intense lightning and transient luminous events (TLEs) from the Cupola window of the orbiting laboratory [1].

The crew used a Nikon Z9 camera with 50 mm F1.2 lens, a camera that has not been applied in such observations before.

2. Observational results

166 forecasted thunderstorm targets, 26 attempted, 15 observed. 7 observation targets yielded imagery featuring TLEs. During the initial review of the recorded media, **8 ELVES, a sprite halo-like event, several blue events (blues)** [2]**, and 1 red sprite** have been found.

Particularly **intense lightning activity** was observed in central and east Africa in the tropical zone, over the coast of South-Carolina, USA, over central China, and above the maritime continent over Indonesia and the Philippines.

The space mission was supported by a **ground-based optical observation campaign** in which a large community of citizen scientists participated from different parts of the globe. Citizen scientists managed to photograph red sprites over two thunderstorms that were forecasted and suggested for observation to the astronauts, alas, those targets were not selected for execution. Record the same TLE from space and from the ground simultaneously remains to be achieved in the future.

Acknowledgement

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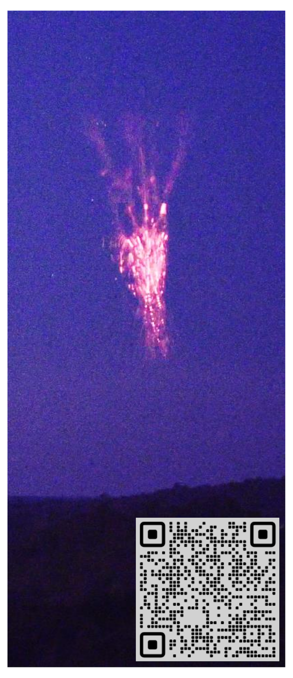
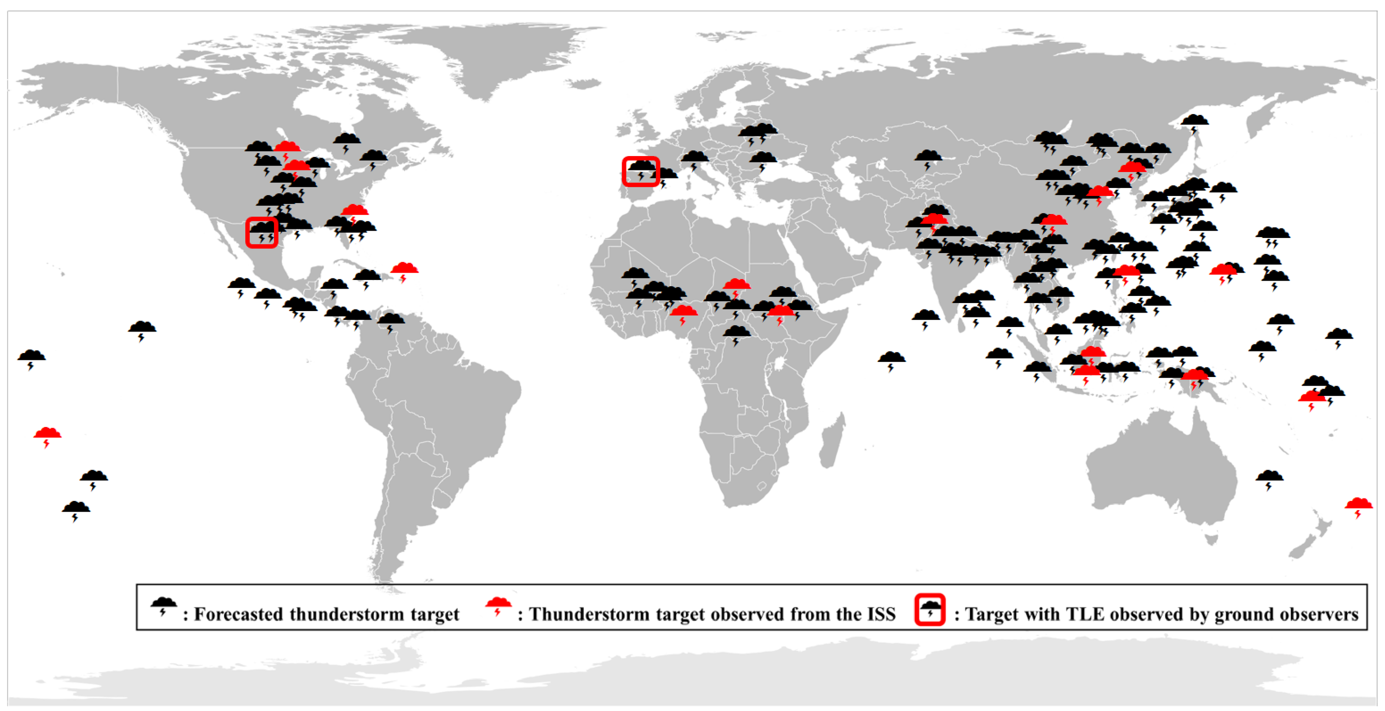
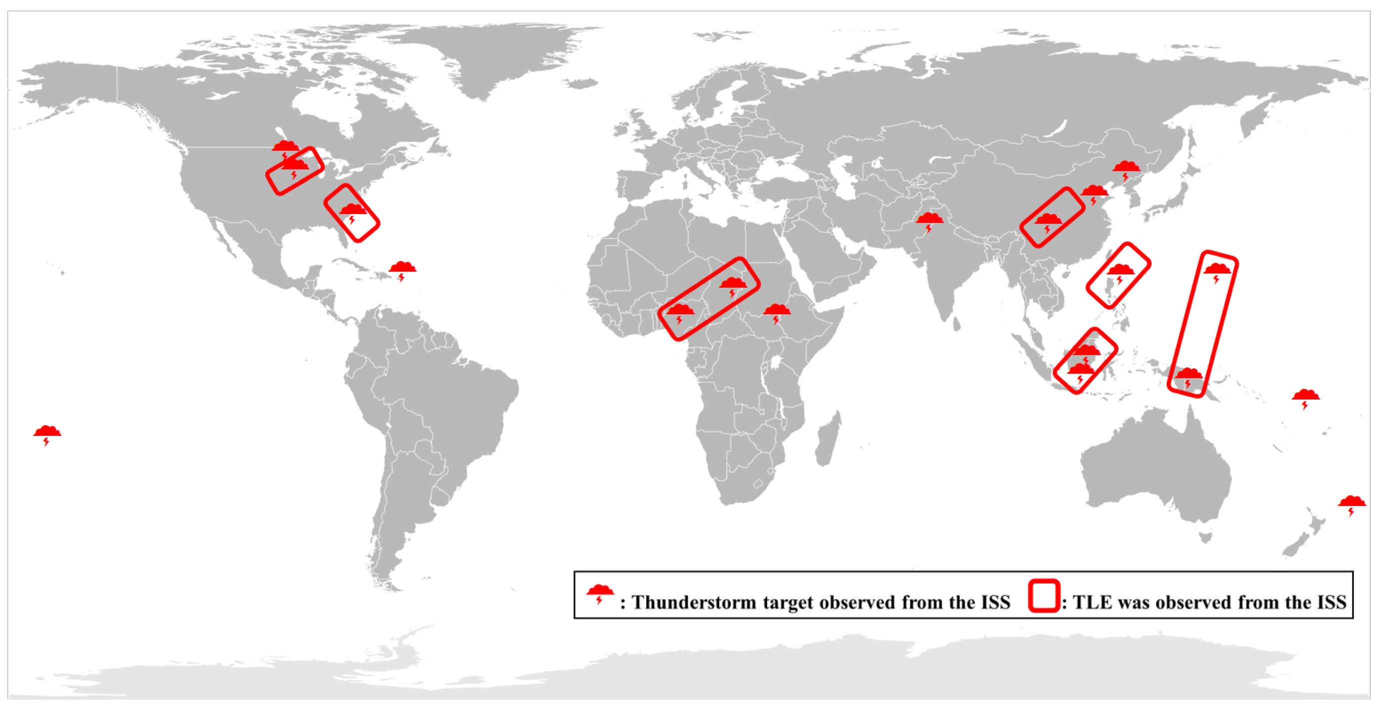
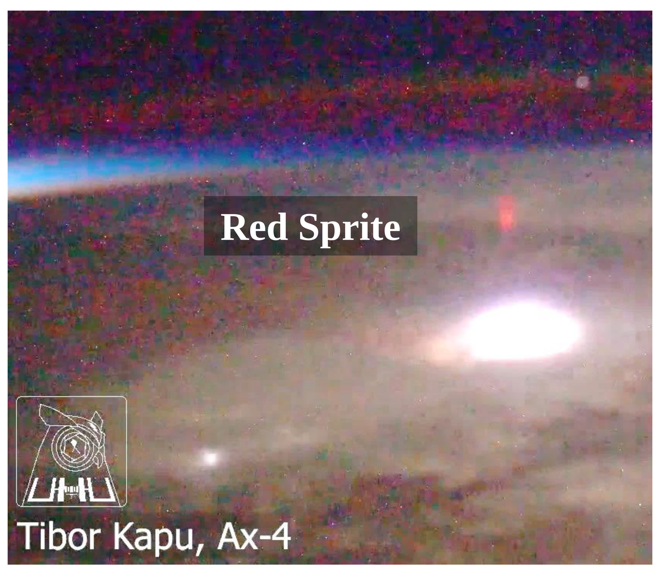


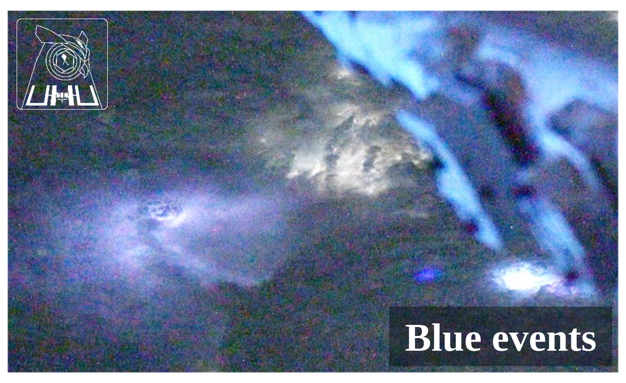
Nicolas Escurat, France
North Spain –
– Bay of Biscay
11 July, 2025

Stephen Hummel
Texas, USA
13 July, 2025





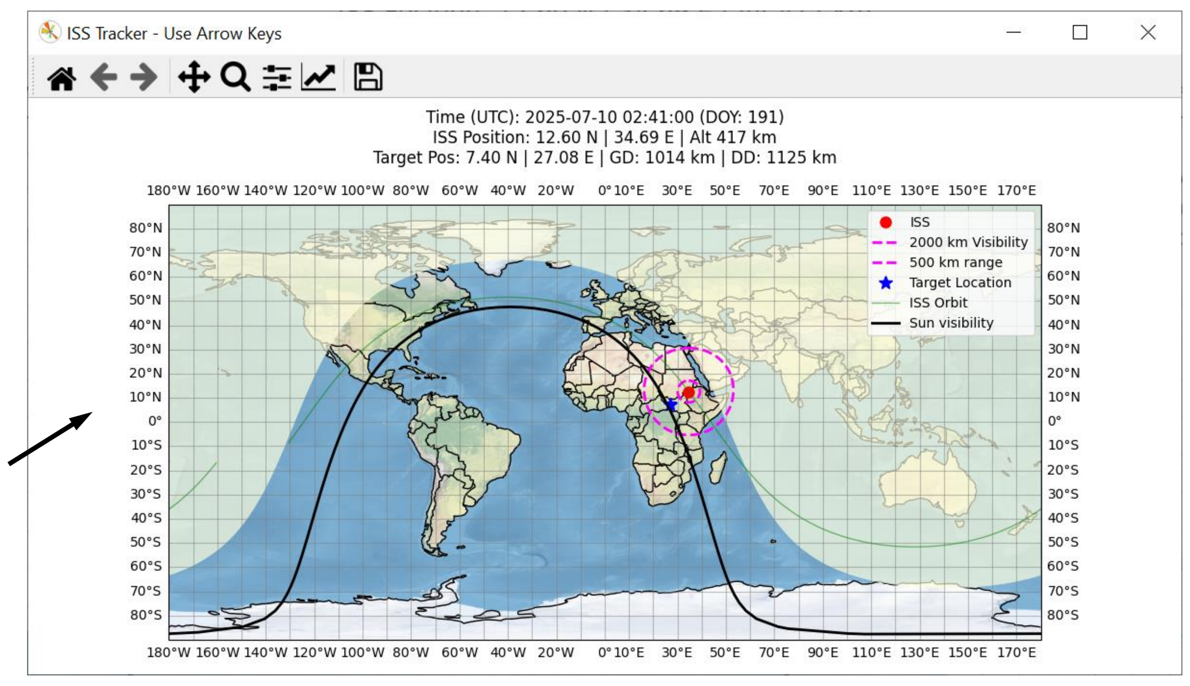


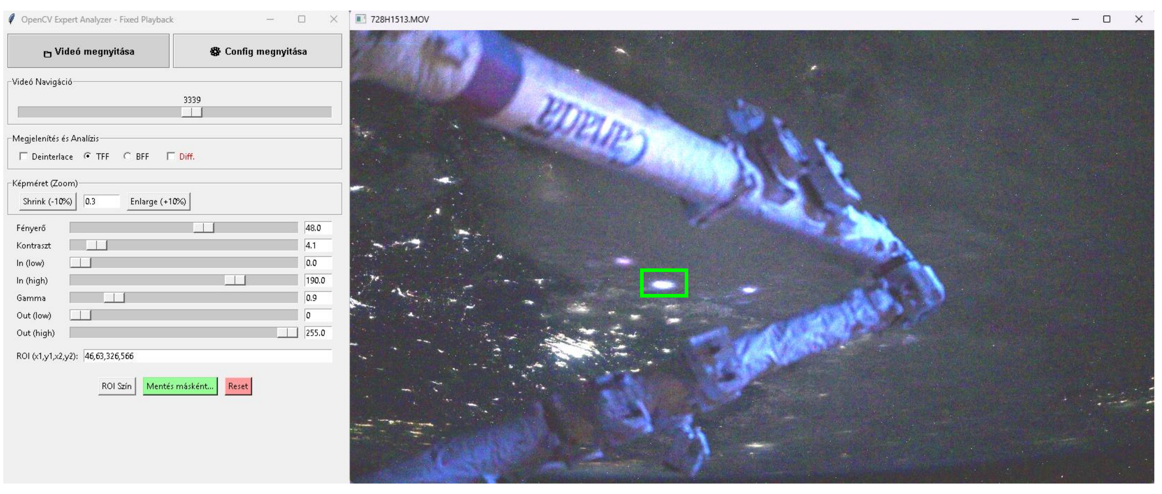


3. Lessons learned

On target forecasting and planning the observations

- **The usual forecasting methodology** [3,4] **worked well** (with utilizing GFS data; to be evaluated quantitatively) even when information only from public commercial weather forecasting services (e.g., windy.com) was taken into account.
- **A Python-based application has been developed to aid planning the observations** and it proved to be a very useful. It features tracking the space-station's position using the so-called two-line-element orbit code (automatically updated), adjustable coarse and fine time stepping, interactive setting of the target position, displaying the day/night regions, different ranges from the space station's footprint, calculation of the line-of-sight and footprint distance of the target, zoomable map view for easy orientation.





On training the astronauts for observing

- Efficient training is crucial for a successful mission: good **skills need to be developed yet on the ground** for the operation of the camera: handling, setup, focusing, direction finding in the cupola, and target tracking [4].

On the importance of communication

- **The communication protocol** between the ground science team and the observing astronauts **must be clearly defined**. The ground science team should have the possibility to
  - **supervise the execution notes** (target information, key camera settings, specific requests, etc.) to support the observing astronauts effectively;
  - **review the recorded footages soon after the target execution**. It can save the mission from failure [4].

On scheduling the observations during the mission

- Astronaut-conducted Earth observations **must be hard scheduled early in the mission time frame** especially for unexperienced astronauts to gain practice in carrying out the activity in microgravity.

Practical experiences

- **No optical observation** of the night hemisphere **was possible in full daylight and during the period of high sun beta angle conditions** when the Cupola has been constantly exposed to direct sunlight.
- **Obtaining accurate time stamps** for camera imagery on the space station **is still a not fully solved challenge** [4]**.**

Post-flight activities

- **Debriefing** of the ground training and the on-orbit operation phases with the observing astronauts must be explicitly planned and scheduled early after the end of the mission.

On collaborating with citizen observers [5]

- **Allow enough time for the preparations.** The background, the motivation, and the goals of the campaign as well as the activities requested from the contributors must be clearly communicated. Having a well-designed website is a great advantage.
- **Use various communication channels** and social media platforms for communicating efficiently. Welcoming and supporting interested applicants require significant efforts.
- **Inform ground-based observers about the targets scheduled for observation** from the ISS. It helps concentrating their efforts and increases the chance for success.
- **Consider the availability and readiness of ground-based observers at scheduling** the space-borne observations.
- **Collecting the observations** and the metadata from citizen observers **can be challenging.** The quality of the observation material varies much.
- **Keep citizen contributors updated** on the progress of the follow-up research work. It carries a positive message and helps maintaining the interest for future joint activities.
- **The results of this mission supports that recording the same TLE simultaneously from space and from the ground is possible in principle.**

4. Research topics to work on

- **Assessing the Probability Of Detection (POD) and False Alarm rate (FAR) of the thunderstorm forecasts** based on meteorological data and lightning location network data (ENTLN, WWLLN).
- Finding the **exact time of the video recordings** by matching the sequence of optically observed lightning with the time series of lightning strokes from lightning databases.
- Finding the **direction of the camera** and characterizing the **spatial resolution** by identifying the stars and matching the ground view in the image frame with geographical (coastlines) and city maps (city lights).
- **Surveying the observed lightning activity**: light intensity, color of lightning lights, duration of the light emissions, synchronicity, etc.
- **ELVES**: finding and characterizing the parent lightning using ELF/VLF-band radio records, geolocation via the ELF/VLF-band radio signals, evaluation of the brightness and size, finding and analyzing the associated VLF LOREs.
- **Blues**: many events - cataloging: color/hue, brightness, optical life time, occurrence rate, location (absolute, relative in the cloud system), relation to storm time evolution and lightning activity, seeking corresponding narrow bipolar events (NBEs)
- **Red Sprite and Halo**: finding and characterizing the parent lightning using ELF/VLF-band radio records, geolocation via the ELF/VLF-band radio signals, evaluation of the brightness and size, finding and analyzing the associated VLF events.
- **Ground-based observations**: creating a catalog of the observed events and available metadata (e.g., time and location).
- Working out an AI-supported framework for **automatic detection of TLEs** in both space-borne and ground-based video records (may utilize citizen science resources)
- Working out an inventory of recommendations **and tools for both citizen and academic observers to aid more relevant contribution to TLE-related scientific investigations.**

Your contribution is most welcome!

5. References

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