Design of an instrument to perform simultaneous multi-band optical and radio observations of lightning

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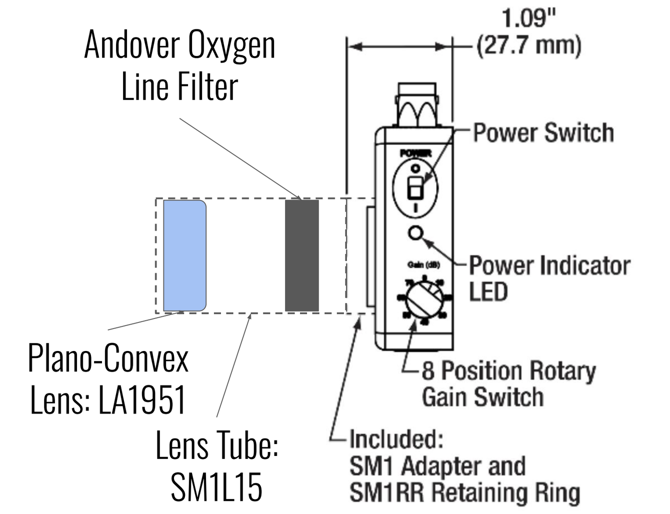
Abstract

Here we report on the design of an instrument to perform simultaneous, multi-band optical and radio observations of lightning. Such measurements are crucial for the complete characterization of lightning flashes, to assess current spaceborne lightning detectors, and to assist the design of future technologies for lightning detection from space. The instrument has three main subsystems: photometer, electric field sensor, and a context camera. Data for the first two subsystems is collected via a PicoScope data acquisition module recording 5 million samples per second, while the context camera is operated at 5,000 frames per second. The instrument records 2 seconds of GPS time tagged data. The photometer has four channels: one broadband (340–1100 nm) plus three narrowband (1 nm) centered at bright oxygen lines in the near infrared. The electric field sensor is composed of a fast and slow channel with decay time constants of 0.1 ms and 10 s, respectively. In this presentation we go into the details leading to particular design choices and show preliminary data collected in the Summer of 2023. Multi-band photometry has the potential to serve as a low-cost tool for detailed plasma physics diagnostic of lightning. Nonetheless, we argue that photometric data needs to be meticulously validated (Wemhoner et al., 2023). Bearing that in mind, here we present comparisons between photometric data with the fast and slow antenna to ENTLN, LMA and GLM.

Experimental Setup

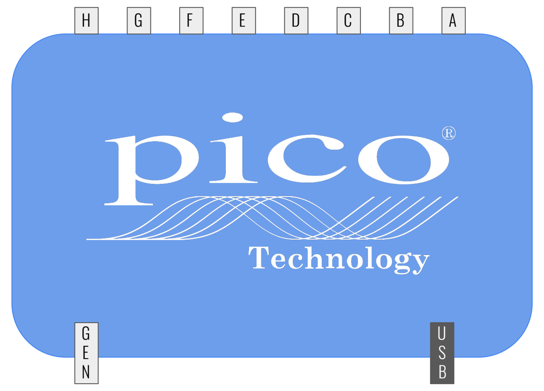


Narrowband gaussian filters:

Center (nm)	FWHM (nm)	Trans. (%)
777.59	1.04	50.46
844.77	1.02	59.50
926.78	1.06	54.90

Figure 1: Image of the Chronos overview camera, with the photodiodes mounted on top of it (left). Diagram of the photodiode optical setup from the Thorlabs Manual for PDA100A2 with adjustments made to account for the added parts(right).

Deployed Instruments:



- PicoScope 4824A at 10 MS/s
- Fast Antenna (τ = 100 μs, A)
- Slow Antenna (τ = 10 s, B)
- 4 Thorlabs PDA100A2 photodiodes (C–F)
- GPS timing unit with 0.1 μs precision (G–H)
- High-speed Chronos context camera (triggered by GEN)

Supporting datasets:
♦ ENTLN ♦ LMA ♦ GLM

Figure 2: Diagram of PicoScope (top). Image of the electric field antenna (bottom).

Results

Flash with multiple return strokes

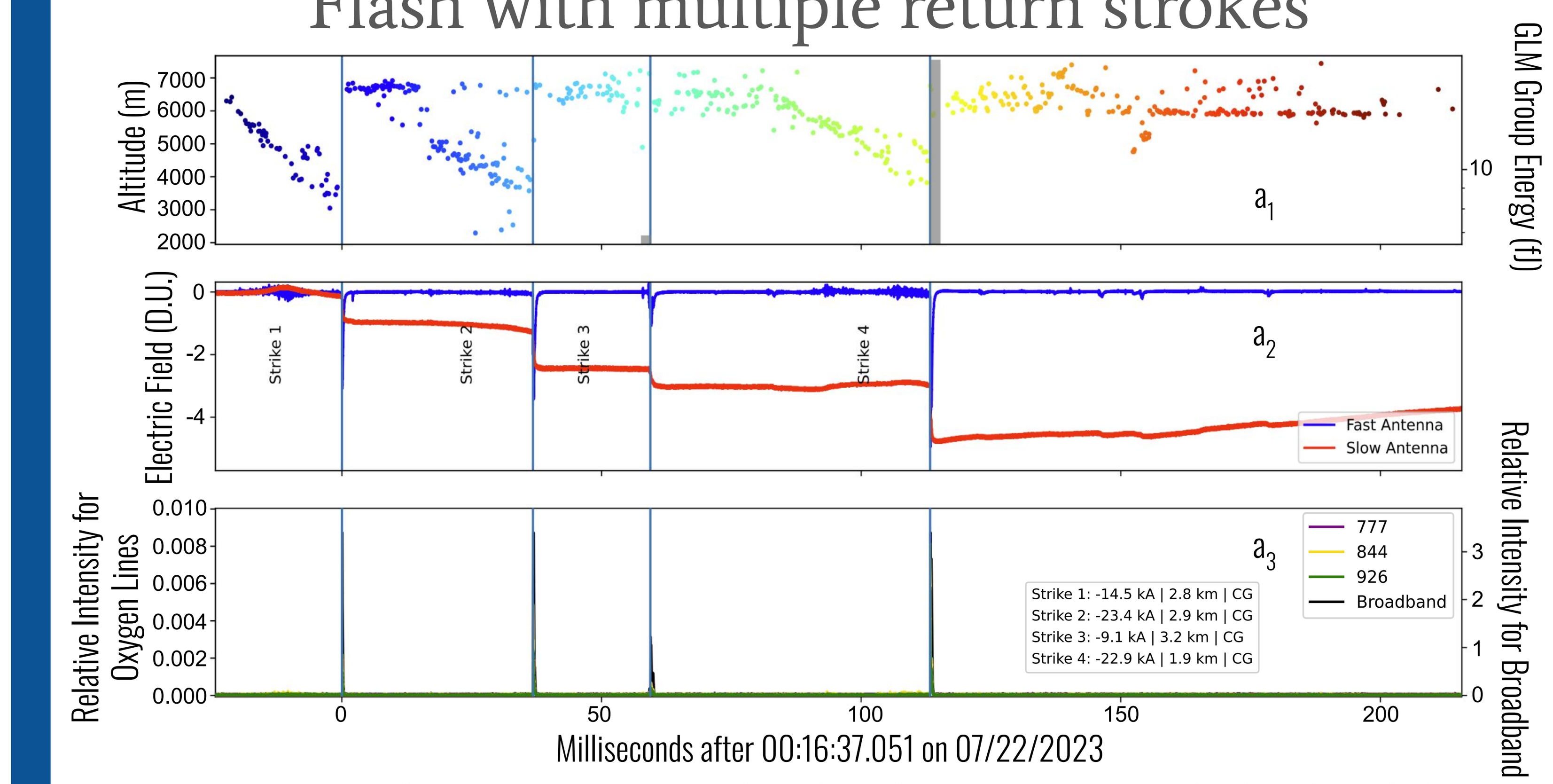
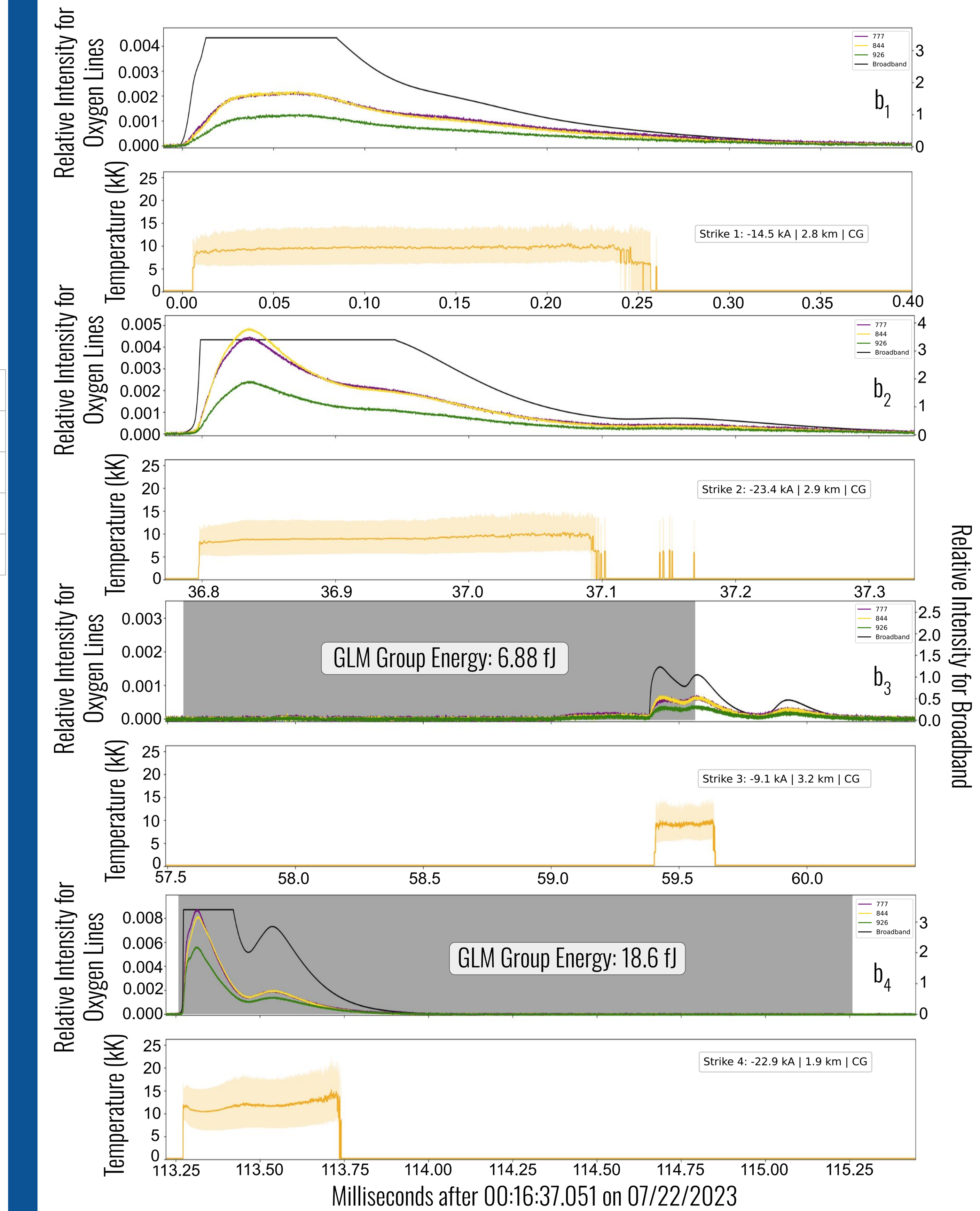
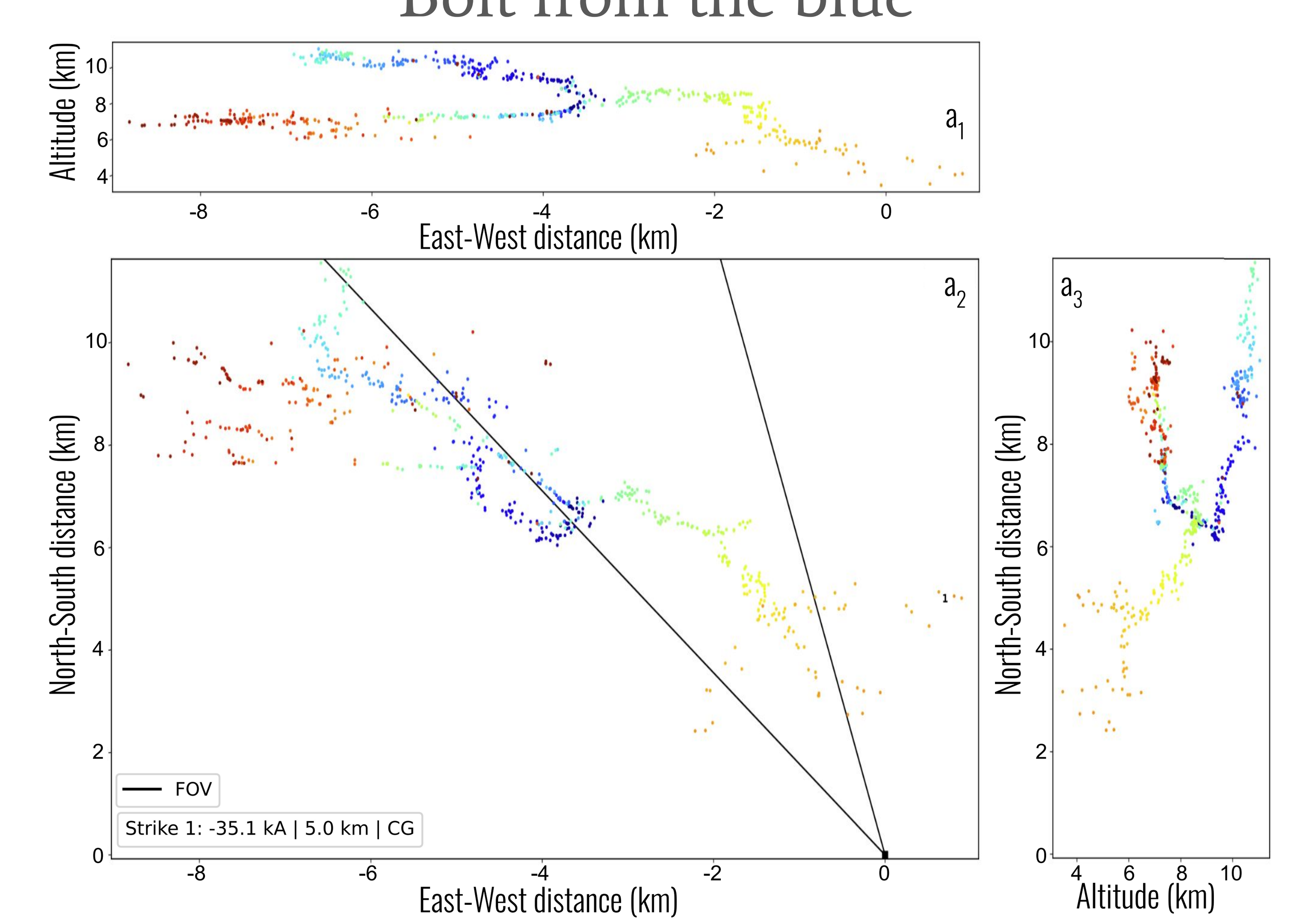


Figure 3a: LMA altitude data, ENTLN strike info, and GLM group energy for the whole flash (a_1). E-field (a_2) and photodiode (a_3) data for the whole flash. Figure 3b: Individual return strokes with the same axes as Figure $3a_3$ for the photodiodes alongside GLM data (top). Temperature for the individual strokes plotted with error bounds (bottom).



Bolt from the blue



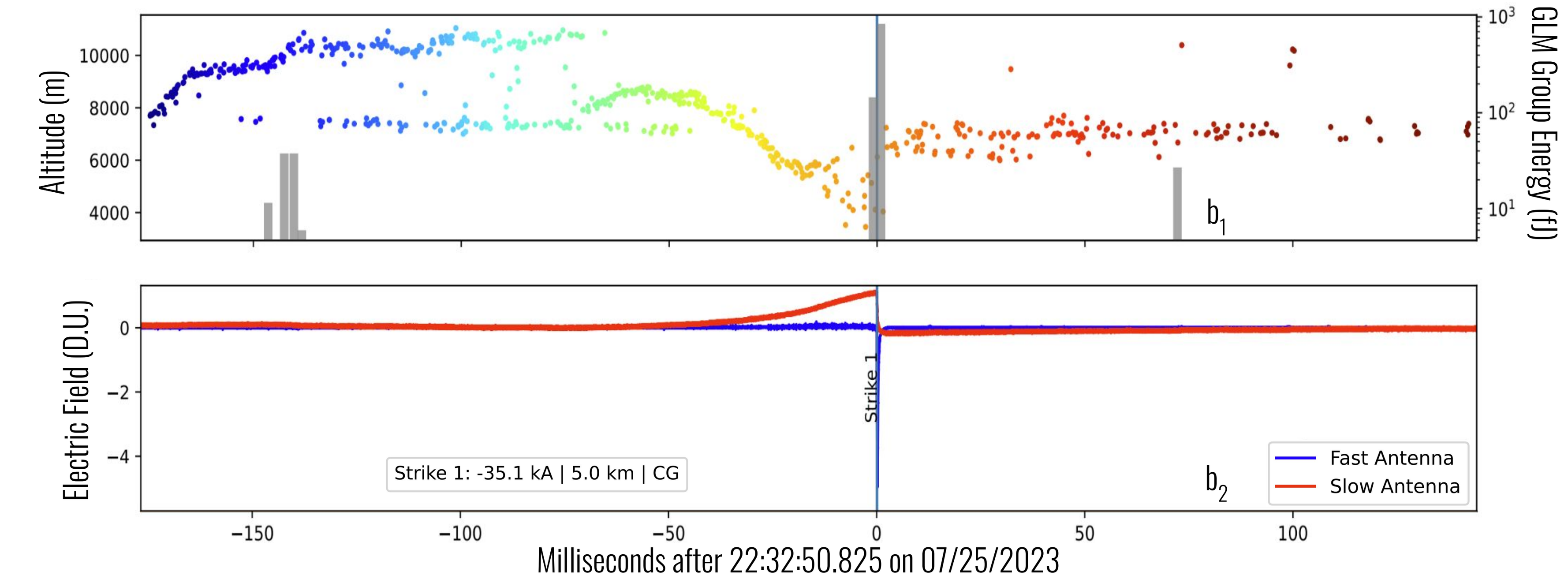
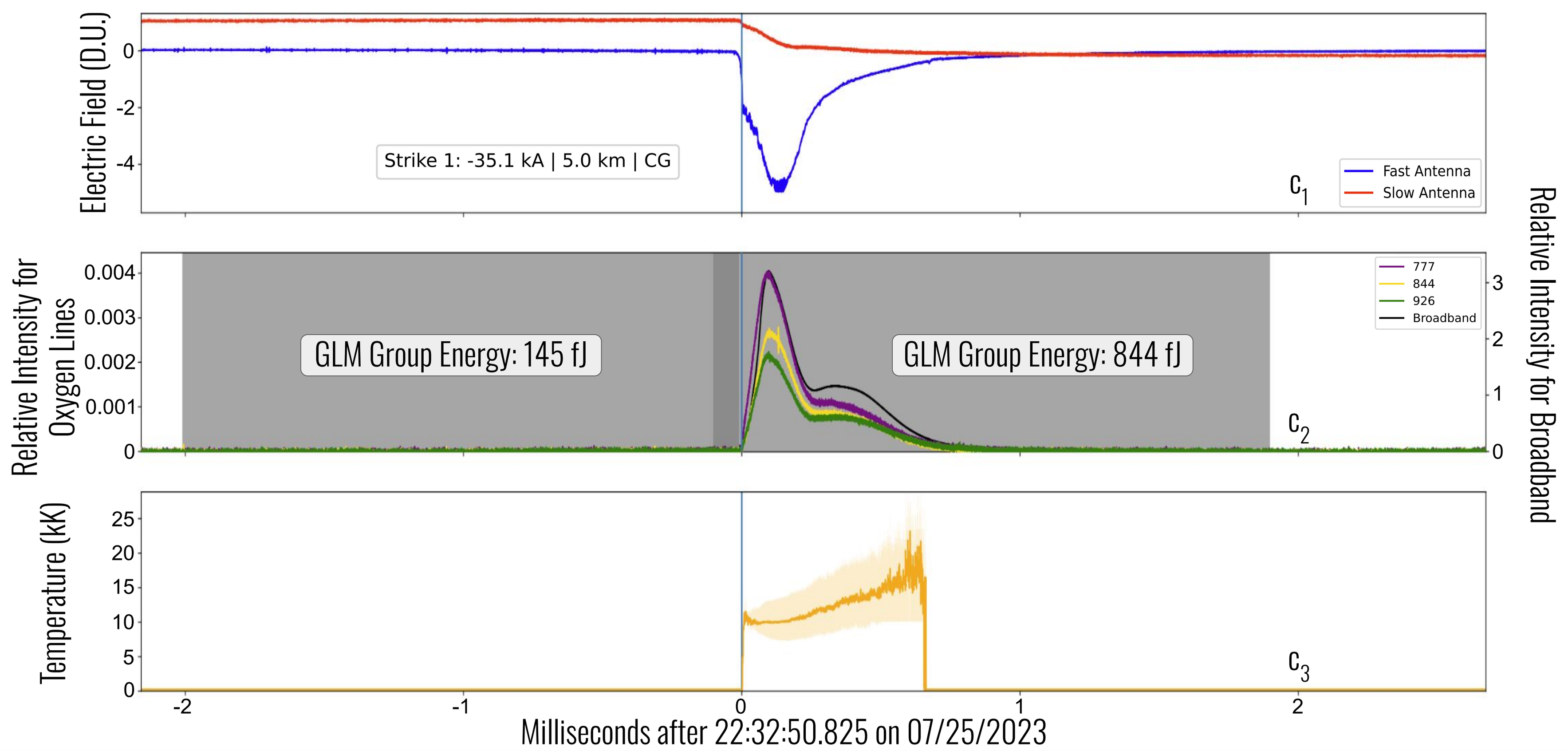


Figure 4a: LMA 3D position colored by time (a). Panel (a_2) is a top down map with both the FOV of the photodiodes and location of ENTLN-reported strike. The entire flash with LMA, ENTLN, and GLM data plotted in a similar manner to Figure $3a_1$ (b_1). E-field record for the whole flash (b_2). E-field (c_1), photodiode intensity and GLM group energy (c_2), and temperature with error bounds (c_3) for the single return stroke in this flash.



Temperature Estimate

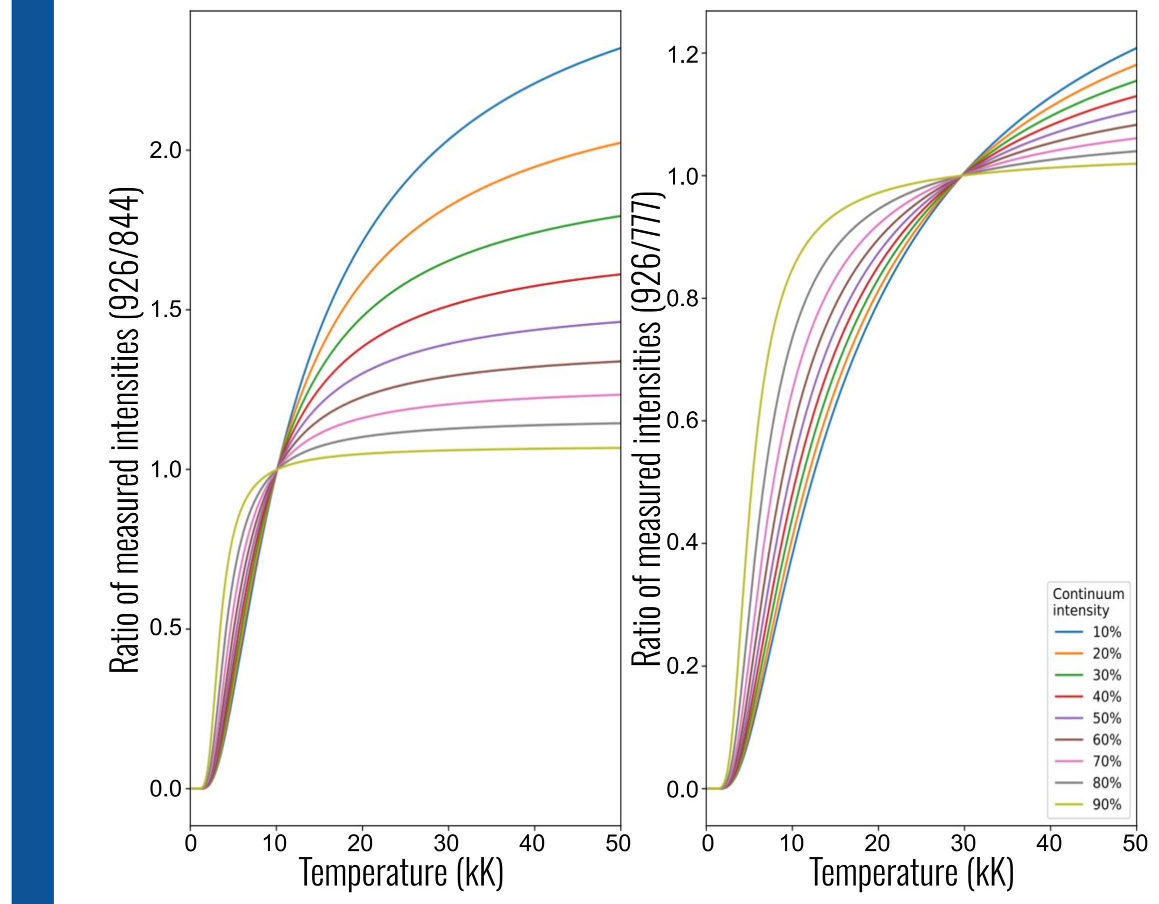


Figure 5: Theoretical ratios of measured intensity for selected lines atomic oxygen lines. The ratios depend sharply on temperature. Curves describe different contributions of continuum emission to the total measurement.

- Line intensity ratios are exclusively functions of temperature (see e.g., Walker and Christian, 2019);
- Continuum is approximately flat around 777–926 nm, and roughly of the order of 30% amplitude (Boggs et al., 2021);
- Not knowing the continuum contribution introduces uncertainty, except when ratios are 1;
- Temperature is determined by interpolating figures above and taking an average of the two estimates at 30% continuum;.
- Error bounds are determined by looking at temperature predictions by individual ratios assuming 10–50% continuum.

Summary

- Developed an automated instrument with coupled optical and radio detection allowing for full flash characterization;
- Photometry reveals subprocesses in the lightning channel such as M-components;
- Multi-line photometry allows for the determination of the return stroke average temperature (averaged in the FOV);
- Average temperatures are around 10 kK, which are not as high as near the ground contact point (30–40 kK);
- GLM and ground-based photometry see different portions of the leader network and return stroke around the 777 nm line;
- Temperature rises faster than optical emissions.

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References

Thorlabs PDA100A2 diagram was an edited diagram from the manual found here: https://www.thorlabs.com/drawings/6739b867fe352edf-53733366-E5F4-AE0F-BAD7BDFBC453F66D/PDA100A2-Manual.pdf

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