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Investigating the relationship between TGF durations and the onset times of the optical pulses and the TGFs

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Abstract:

We investigate and determine the sequence of the Terrestrial Gamma-ray Flashes (TGFs) and the observed optical emissions associated with lightning flashes, as well as the connection between the duration of TGFs and the time between the onset of the TGFs and the observed main optical pulses. Over 200 observations from the instruments of the Atmosphere-Space Interactions Monitor (ASIM) on board the International Space Station (ISS) are used, together with data from the lightning detection networks GLD360 and WWLLN. The ASIM data consist of two separate recordings: High energy measurements from the Modular X- and Gamma-ray Sensor (MXGS), and optical measurements from the Modular Multi-Spectral Imaging Array (MMIA). The optical measurements are from photometers operating in the 337 and 777.4 nm bands, and the temporal uncertainty between the two instruments of ASIM is +- 5 μs.

Data:

The data used for this research is gathered from 220 events with a simultaneous MMIA - MXGS trigger from the period 28.04.2019 to 30.11.2020, consisting of High energy measurements, 337 and 777 nm photometre data and 337 and 777 nm camera images. During this period the uncertainty between the MXGS and MMIA instruments is +- 5 µs.

Events:

The events are sorted into three categories based on if the TGFs are within or outside the MMIA FoV, or if the event location of the TGF is uncertain.

Category	Number of events
Within MMIA FoV	81
Outside MMIA FoV	109
Uncertain	28

To determine if the TGFs are within or outside the MMIA FoV we go through each event and take into account the following:

- Observed optical data from the photometres (focusing on 337 and 777 nm)
- Surrounding lightning activity
  - Are there multiple clusters of lightning activity close to the time of the TGF? Only before/after?
- TGF, optical pulse and sferic characteristics
  - Expectations
- Use GLD360 sferics for timing corrections and location determinations where possible

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Data example of event on 09.11.2019 - 13:41:28

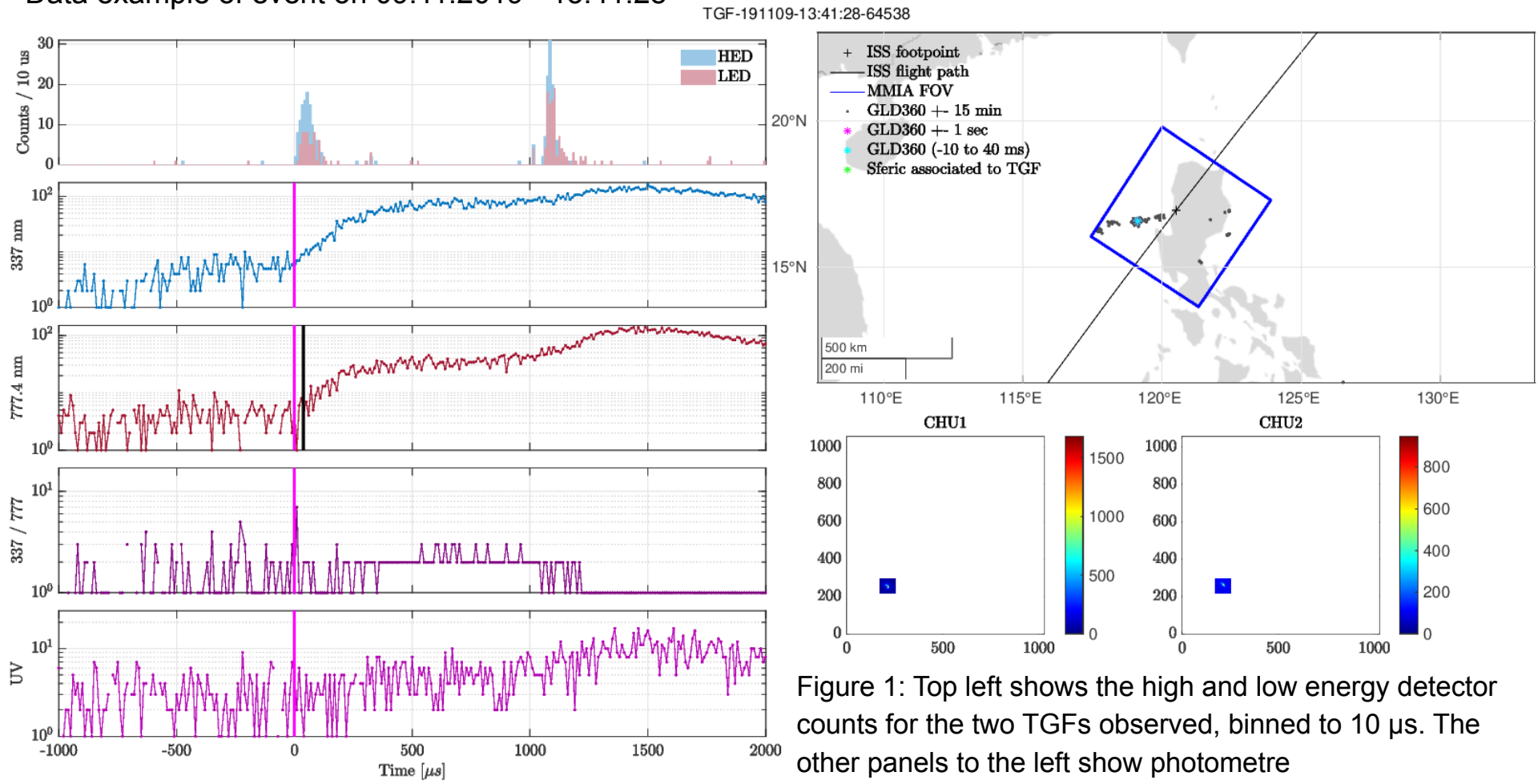

Figure 1: Top left shows the high and low energy detector counts for the two TGFs observed, binned to 10 μs. The other panels to the left show photometre data in raw channels for 337 nm, 777 nm, 337 / 777 nm and 180-230 nm bands. The magenta line shows the time of the first photon of the TGF. The map to the right show the MMIA FoV, with associated sferic activity around the TGF time (+- 1000 s). The two bottom images show the camera images for the frame containing the TGF, where up is in the velocity direction of the ISS (black line going rightwards).

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Fit example for the first event on 09.11.2019 - 13:41:28

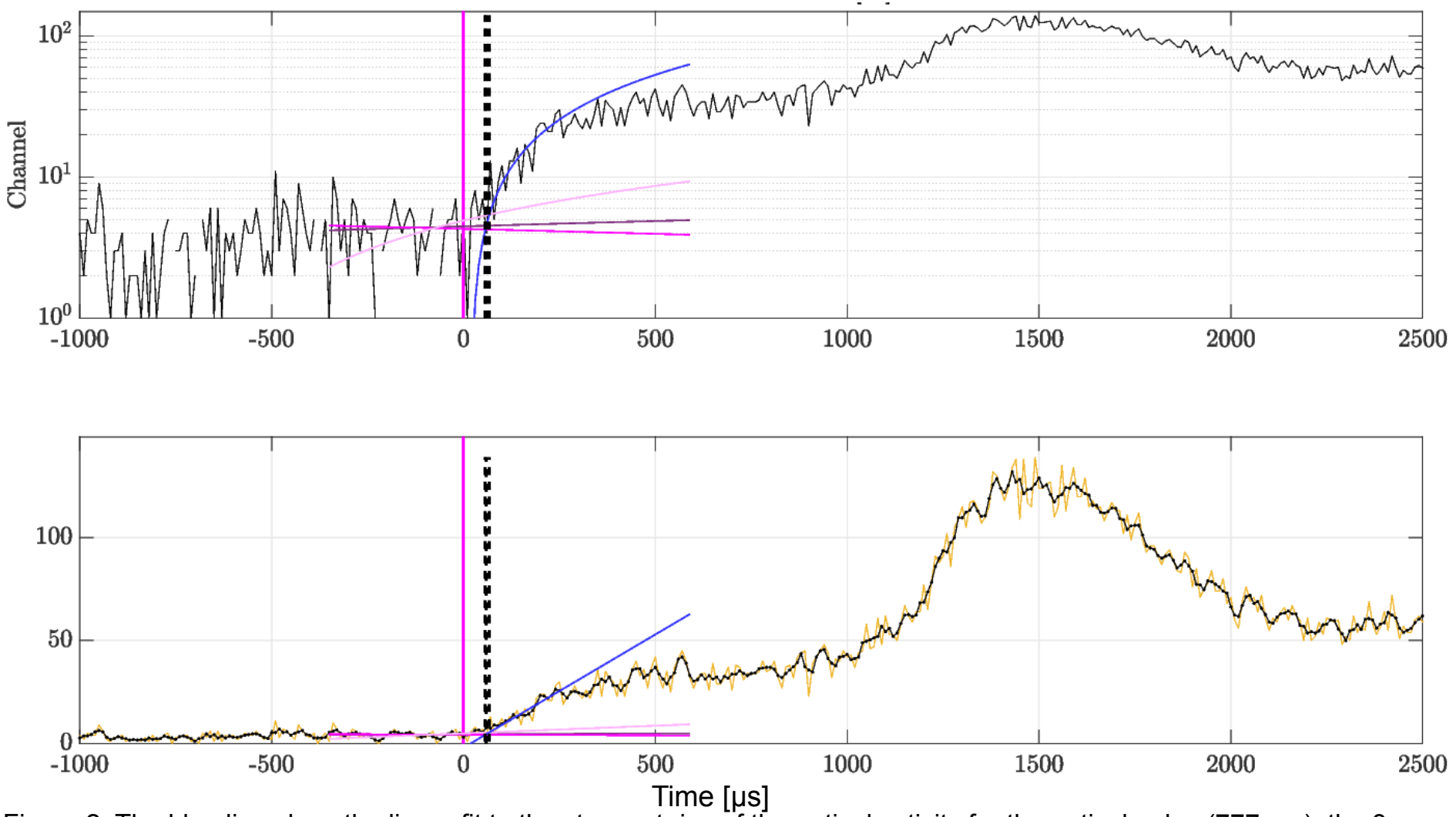

Figure 2: The blue line show the linear fit to the steepest rise of the optical activity for the optical pulse (777 nm), the 3 purple lines show a linear fit to the pre-activity. The dotted lines show the different intersections from the different fits for the pre-activity and the steepest rise. The figure is shown both with logarithmic axis and normal axis.

GLD360 used for timing correction and location determination. The blue line shows the raw data, the yellow lines are a running average over 30 µs. Using the measured optical pulses we determine a timing correction for 94 of the events, where 52 GLD360 sferics are aligned to the optical pulse associated with the TGF.

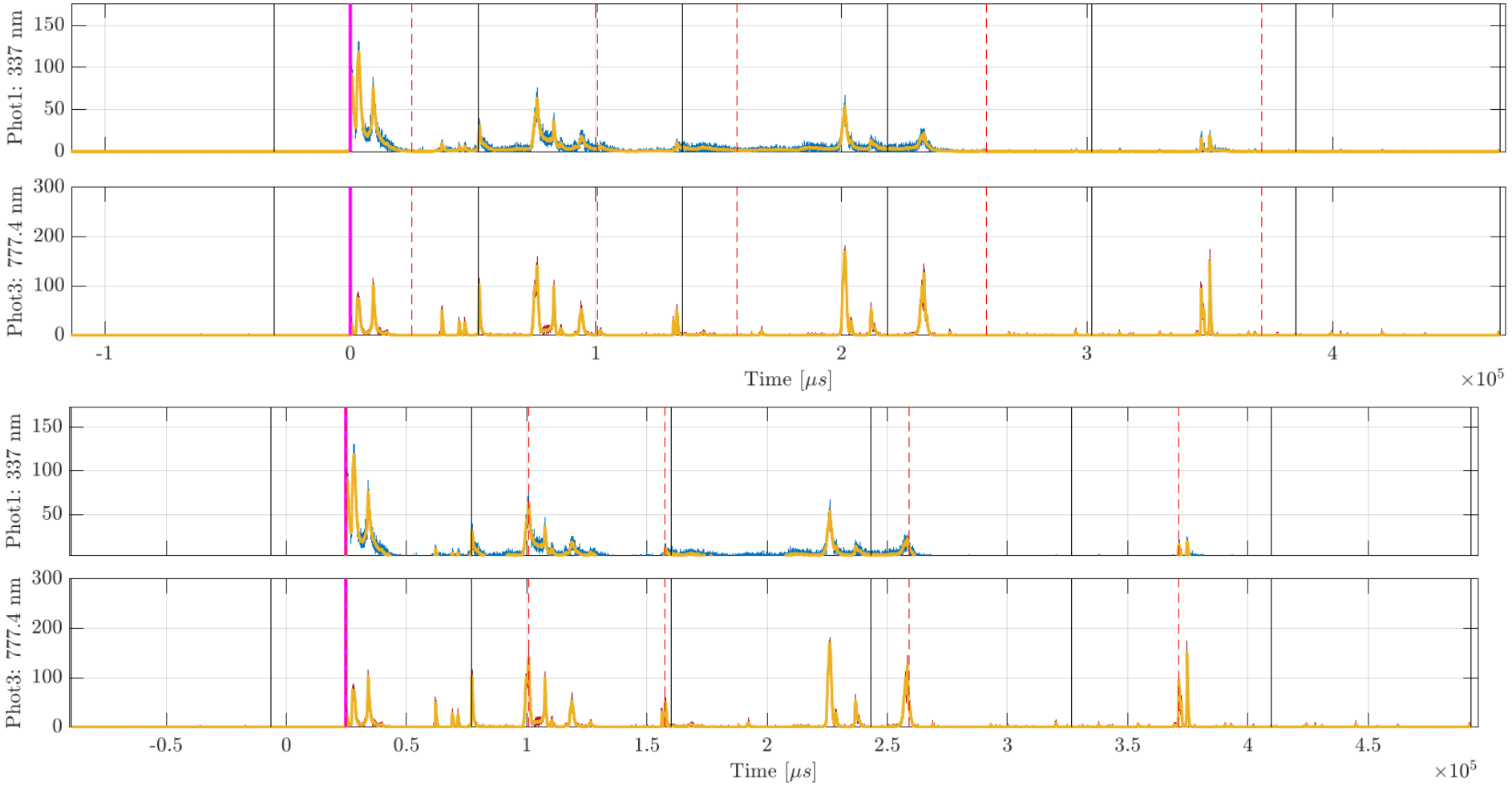

Figure 3: Unshifted (top 2 panels) and Shifted (bottom 2 panels) 337 and 777 nm photometre data aligned with GLD360 sferics (red dashed lines). Magenta line shows the time of the first photon of the TGF

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TGF durations (t_{core90})

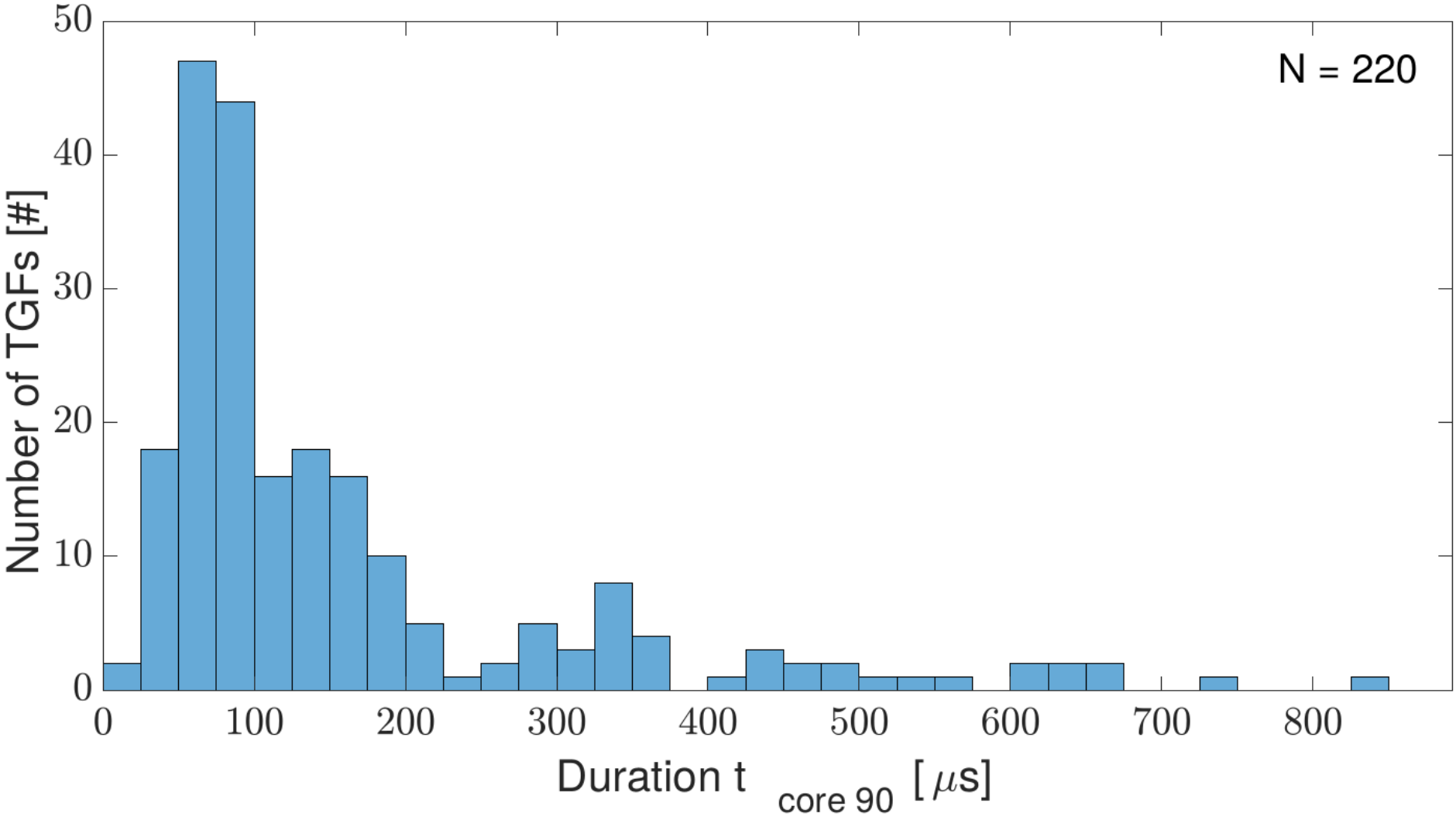

Figure 4: TGF core 90 duration in μs for the 220 TGFs with simultaneous MMIA trigger

Difference in time between onsets of the events within MMIA FoV. No optical onsets before TGF onset.

- Cloud scattering

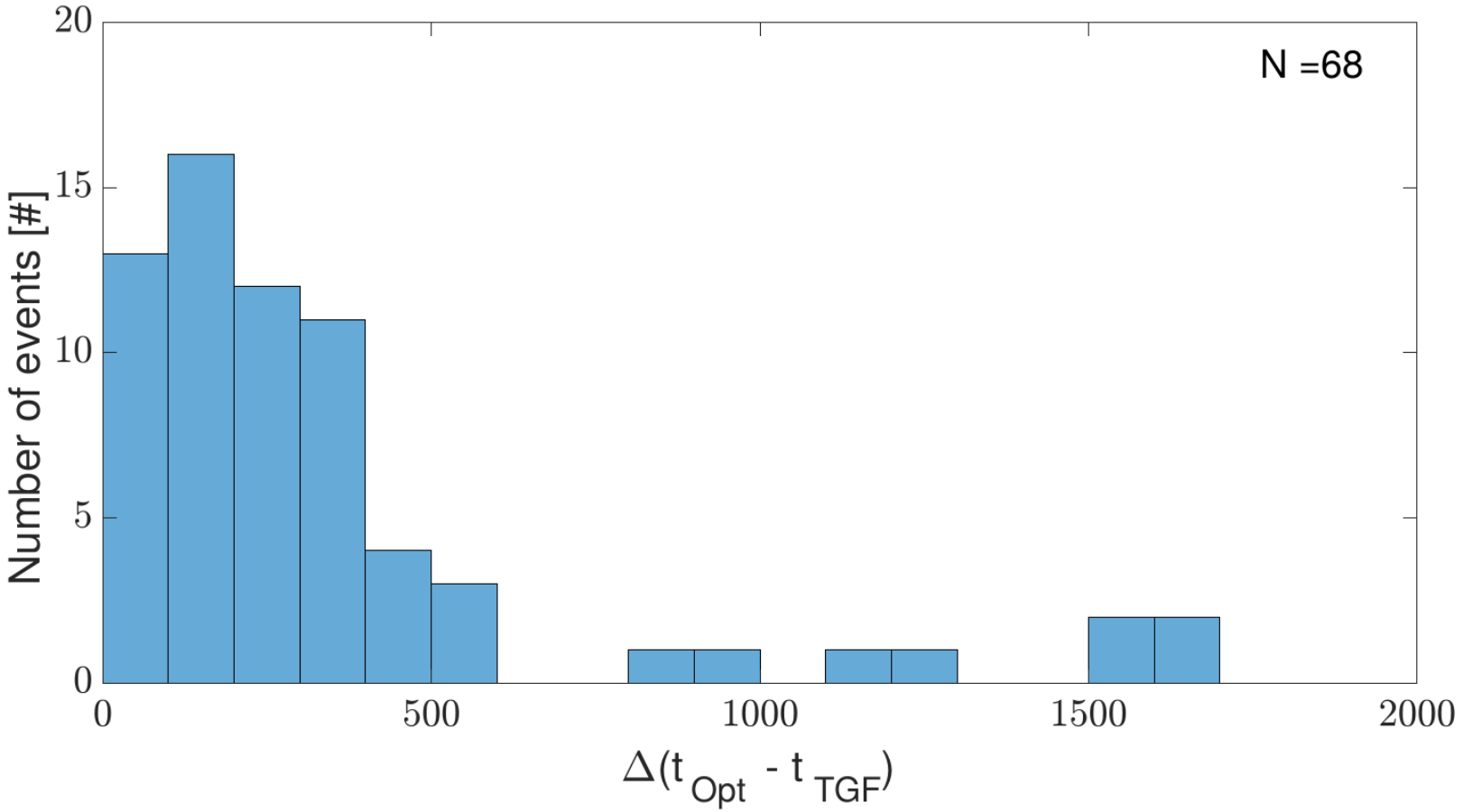

Figure 5: Difference in time between onset of TGF and 777 Optical pulse for the events within MMIA FoV. Bin size = 100 µs, uncertainty between MXGS and MMIA = +-5 µs.

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TGF duration vs Optical onsets. Uncertainties will be added as the difference from the average onset times found from the intersecting linear fits.

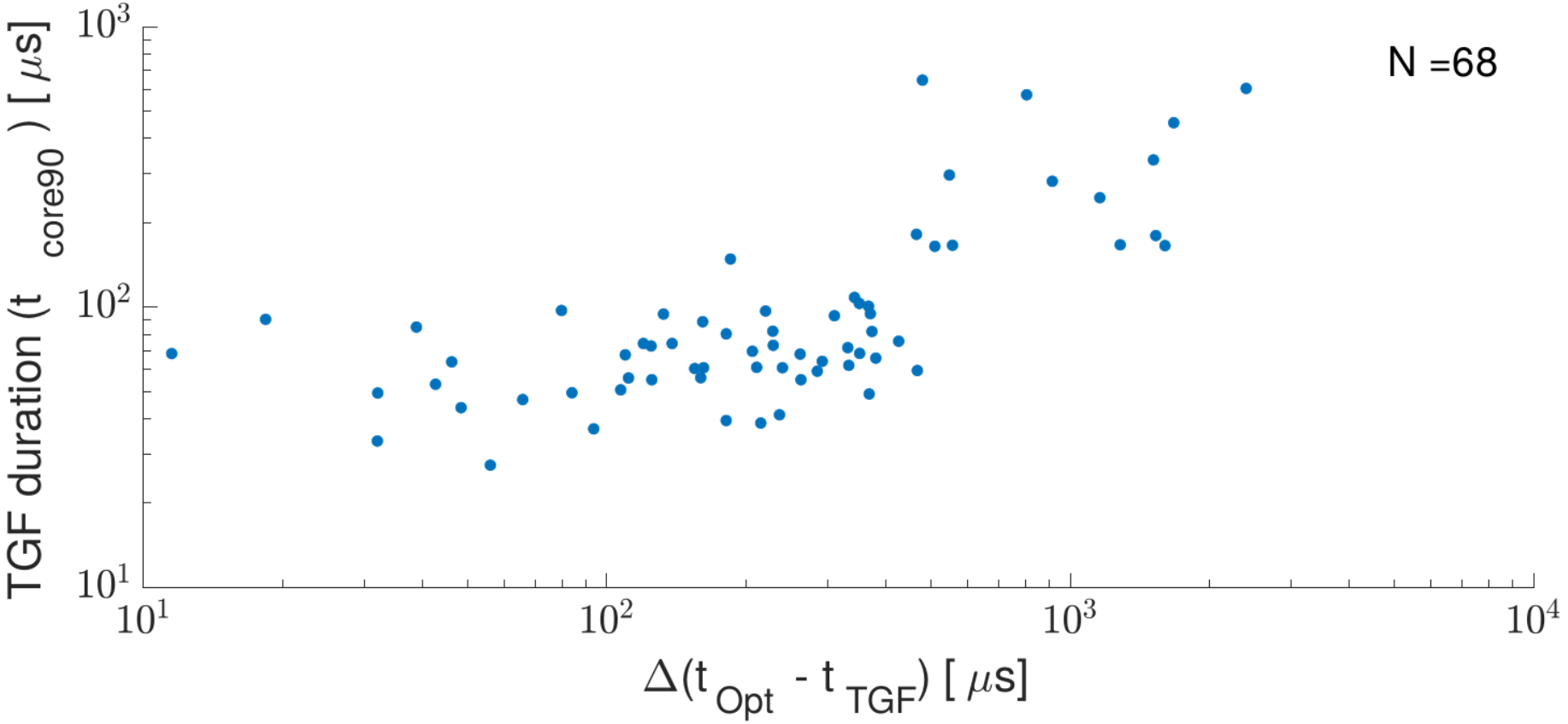

Figure 6: The connection between the TGF (core 90) duration and the optical pulse onsets (777 nm) for the events within MMIA FoV

- 220 TGFs with simultaneous MMIA trigger.
  - 81 of the events found to be inside MMIA FoV, 68 where an onset for the optical pulse can be determined.
- TGFs are produced before or at the onset of optical pulses
  - All TGFs observed with onset before the optical pulse onsets
    - Cloud scattering taken into account
- The TGF durations and delay between onset of TGFs and optical signal appear to be related

- Østgaard et al. (Accepted Manuscript), Simultaneous observations of EIP, TGF, Elve and 2 optical lightning. JGR Atmospheres. doi: 10.1029/2020JD033921

- Chanrion et al. (2019), The Modular Multispectral Imaging Array (MMIA) of the ASIM Payload on the International Space Station. Space Science Reviews. doi:10.1007/s11214-019-0593-y

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- The TGF durations and delay between onset of TGFs and optical signal appear to be related