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Observations of Terrestrial Gamma-ray Flashes at the Telescope Array Cosmic Ray Detector.

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Terrestrial Gamma-ray flashes (TGFs) are bursts of gamma-rays initiated in the Earth's atmosphere by atmospheric lightning. The Terrestrial Gamma-ray flashes discussed in this work were detected at ground level between 2014 and 2018, by the Telescope Array Surface Detector (TASD), a lightning mapping array installed in 2013, and a broadband interferometer and fast sferics sensor installed in 2018. The TASD is a 700 km^2 ultra high energy cosmic ray detector in the southwestern desert of Utah, U.S.A. It is composed of 507 (3 m^2) plastic scintillator detectors on a 1.2 km square grid. In 2013, a Lightning Mapping Array (LMA) detector and a Slow antenna (SA) were installed at the TASD site. The LMA is a three-dimensional total lightning location system, comprised of nine stations located within and around the TASD array. The SA records the electric field change in lightning discharges. The TASD has become one of the world leading instruments for detection of TGFs from the ground. The downward Gamma-ray showers observed by the TASD detector were all confined to the first 1-2 ms of intracloud and cloud to ground discharges, spanning an overall duration of several hundreds of microseconds. We hypothesize that the observed TGFs are similar to those detected by satellites, but that the TASD ground-based observations are able to detect both the temporal distribution at the source and the full footprint of the gamma shower on the ground. More importantly, the gamma ray bursts observations suggest that the TGFs were produced by one or two particularly energetic leader steps at the initial breakdown pulse (IBP) stage. To determine such correspondence, an interferometer (INTF) and a fast antenna were installed a few kilometers east of the TASD detector on July 2018. With this suite of lightning detection instruments together with the TASD cosmic ray observatory, LMA, and SA, we are able, to present, for the first time, observations of the TGFs clearly associated with the IBPs of downward cloud-to-ground flashes and intracloud flashes. This result sheds new light on the origins of Terrestrial Gamma-ray Flashes.

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1. Introduction

The Telescope Array collaboration has previously reported [1, 2] the observation of "bursts" of Surface Detector (TASD) triggers in coincidence with lightning strikes recorded by the National Lightning Detection Network (NLDN) [3]. In each case two or more TASD triggers occurred within less than a millisecond and were found to be in good temporal and spatial coincidence high-current intracloud lightning.

Motivated by these observations, as well as by recent efforts to understand [4, 5, 6, 7, 8, 9] the *Terrestrial Gamma Flashes* (TGFs) observed by satellite-borne detectors [10, 11], a suite of lightning mapping (LMA) and electric field-measuring instruments were deployed at the Telescope Array detector site in Western Utah, U.S.A. The first joint observations with the TA/LMA instruments were reported at the previous ICRC [12] and elsewhere [13]. As reported, the evidence suggests we are seeing gamma ray showers from downward-propagating negative leaders, consistent with a downward version of the TGF phenomenon.

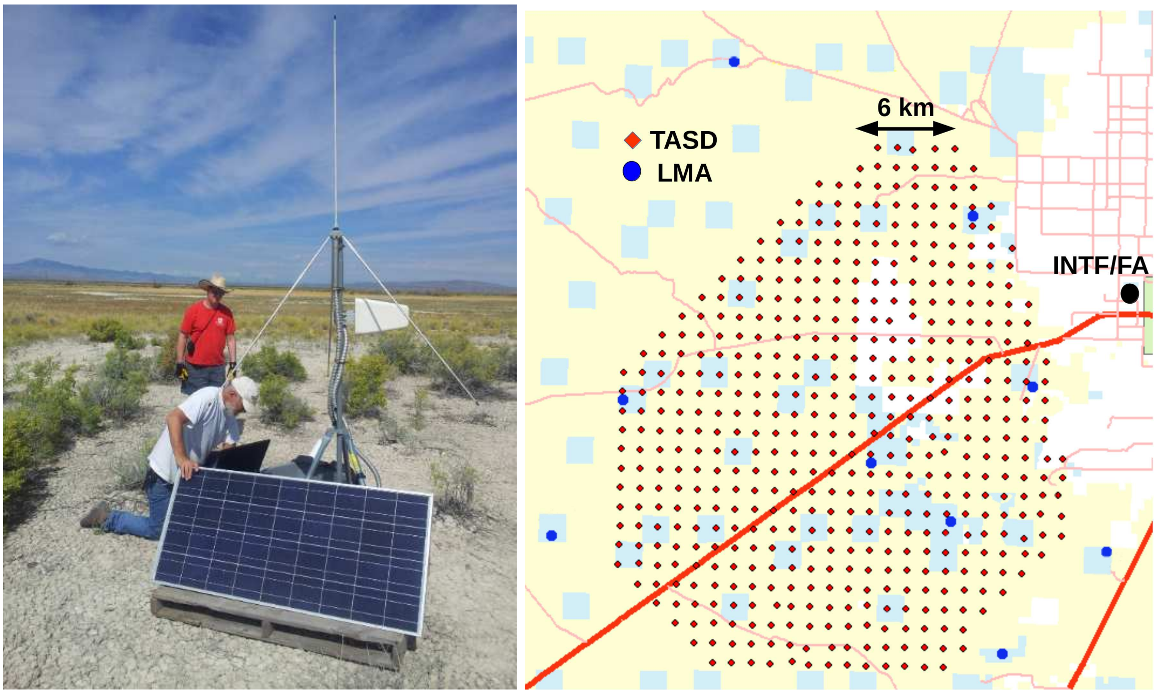

Figure 1: *Left:* W. Hanlon (Utah) and W. Rison (New Mexico Tech) installing VHF Lightning Mapping Array detector at TA site. *Right:* Map of Telescope Array observatory. The 1.2 km grid of surface detectors is represented by red circles, and LMA detectors by blue circles. The location of the recently-installed Fast Antenna sferics sensor (FA) and broadband interferometer (INTF) is represented by a large black circle.

2. Broadband Interferometer and Fast Sferics Sensor

Figure 2: *Left:* One of three flat-plate antennas, on a 120 m triangular base, recording VHF between 20-80 MHz for the broadband interferometer system. *Right:* Fast antenna "sferics sensor", recording electric field changes at 180 MHz.

Motivated by the previous findings, new lightning detection equipment was added to the suite of instruments at Telescope Array in the summer of 2018. This equipment is shown in the photographs in Figure 2, and an example of the interferometer data for an energetic cloud-to-ground lightning strike is shown in Figure 3.

3. Conclusion

The most recent results from the Telescope Array Lightning Observatory will be presented at the 36^{th} International Cosmic Ray Conference.

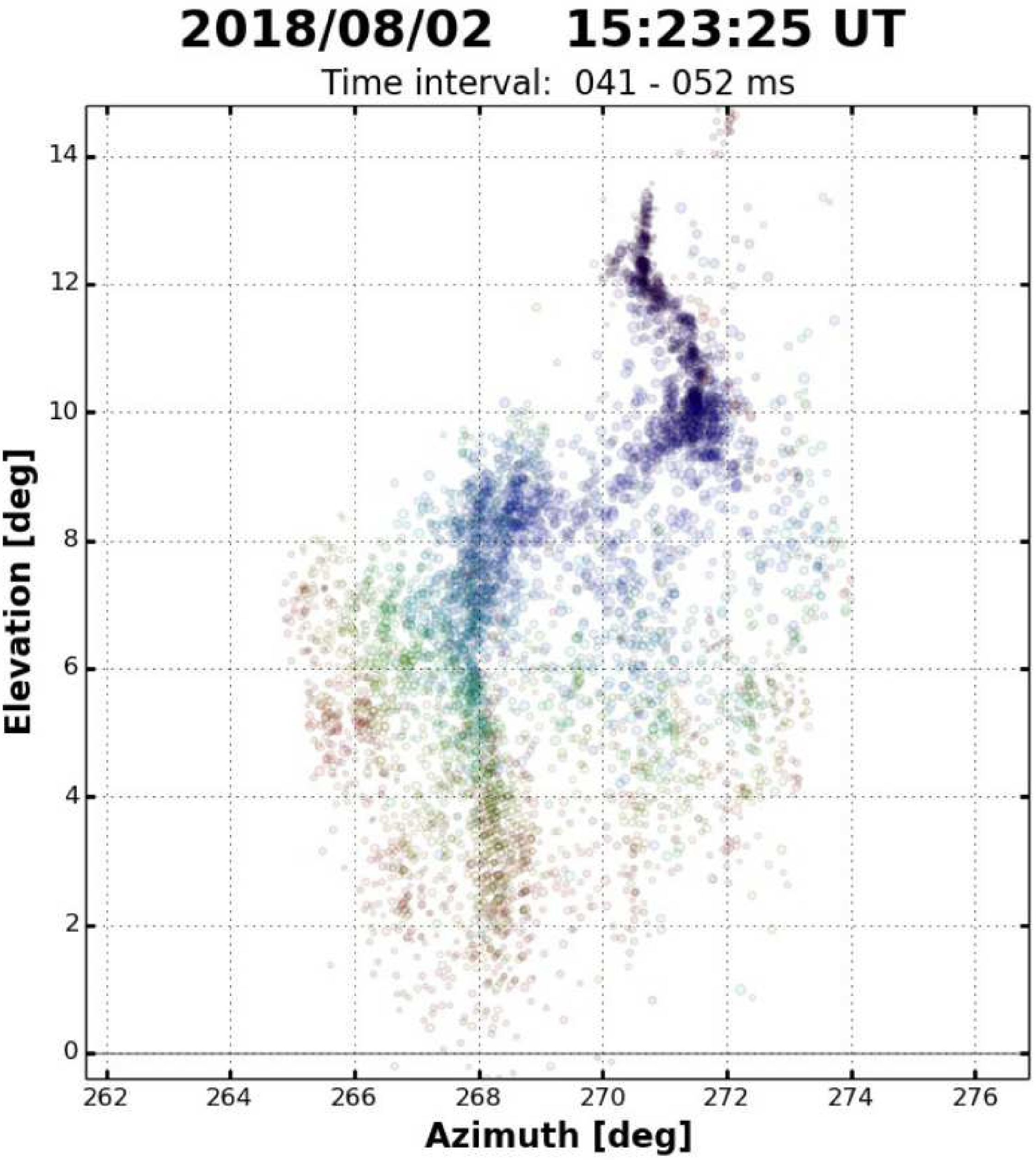

Figure 3: Elevation versus azimuth reconstructed from broadband interferometer (INTF) data, for an energetic cloud-to-ground strike observed over the Telescope Array Surface Detector on 2 August 2018. This event, recorded less than a week after installation of the interferometer and spherics sensor, was one of the first TGF events recorded with this detector configuration.

4. Acknowledgements

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