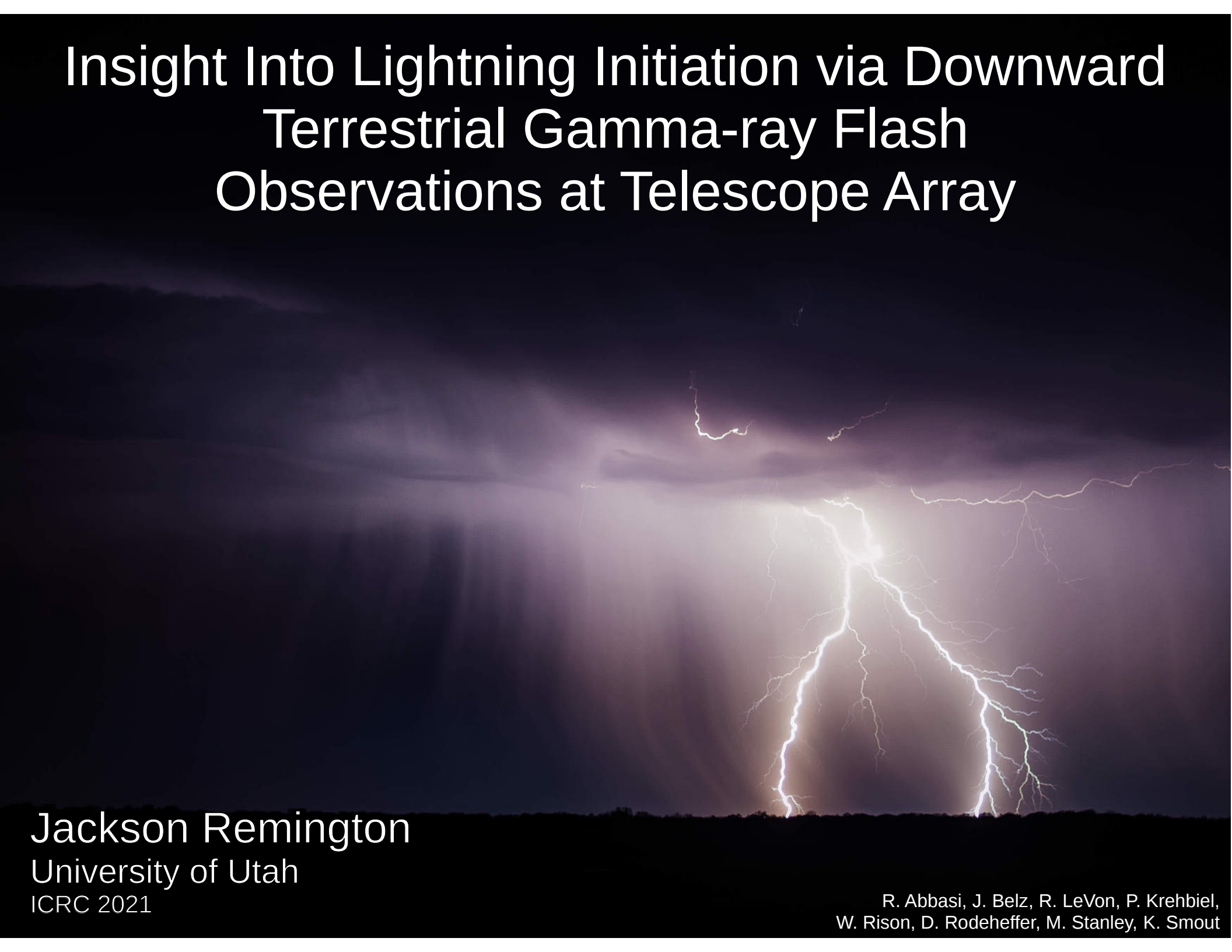
Insight Into Lightning Initiation via Downward Terrestrial Gamma-ray Flash Observations at Telescope Array



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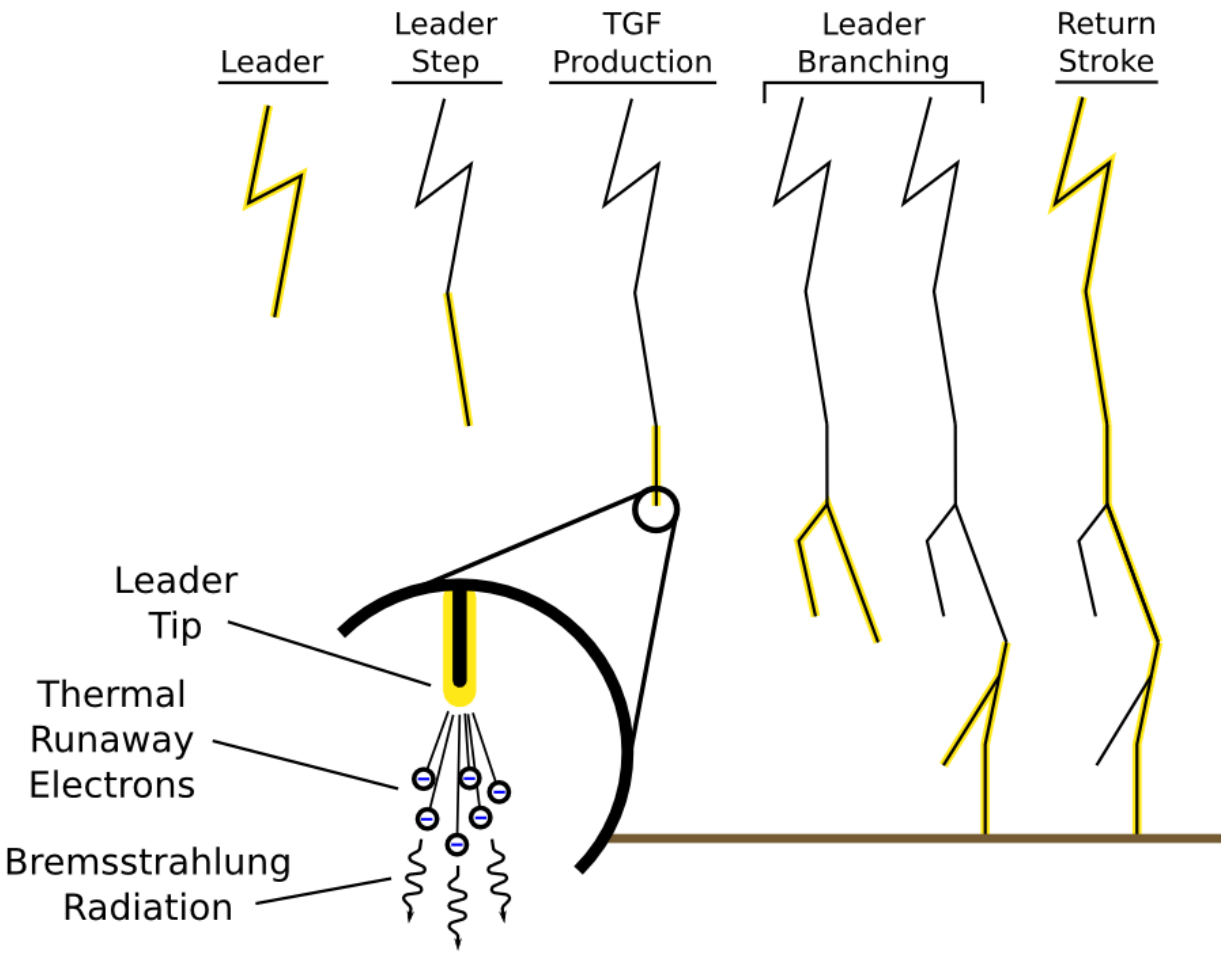
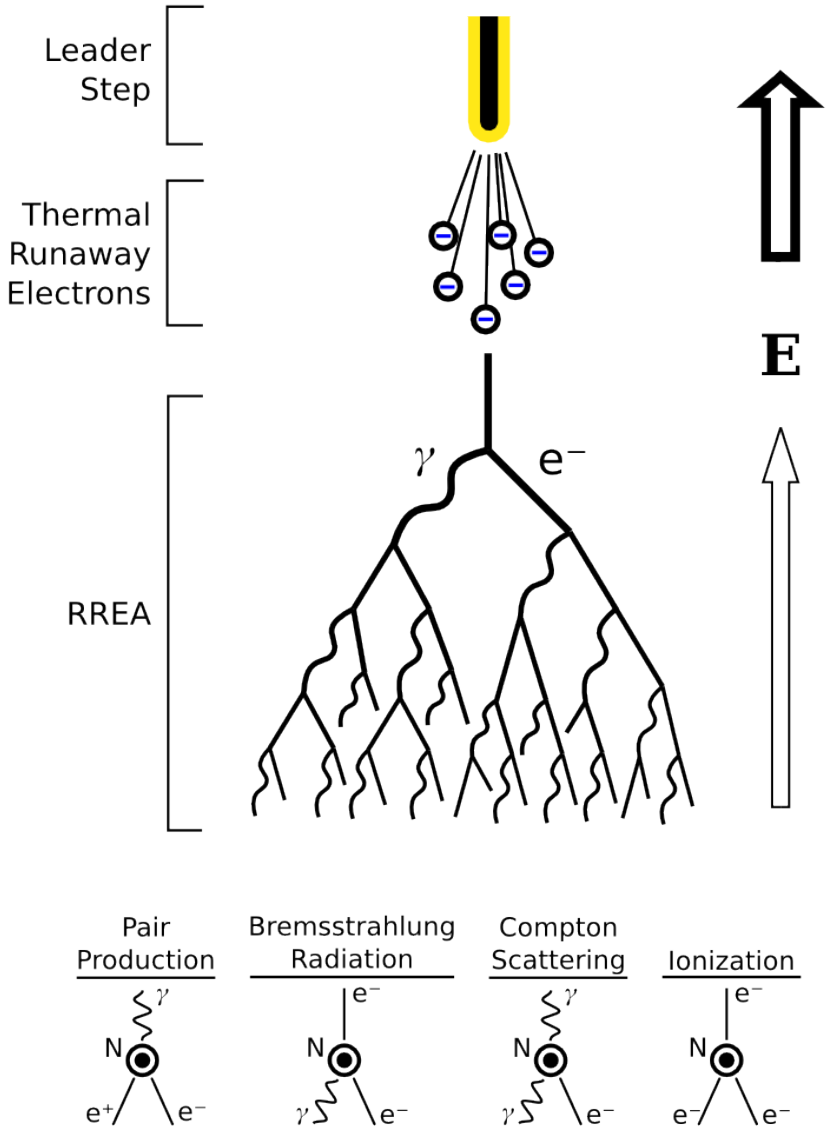
Lightning 101



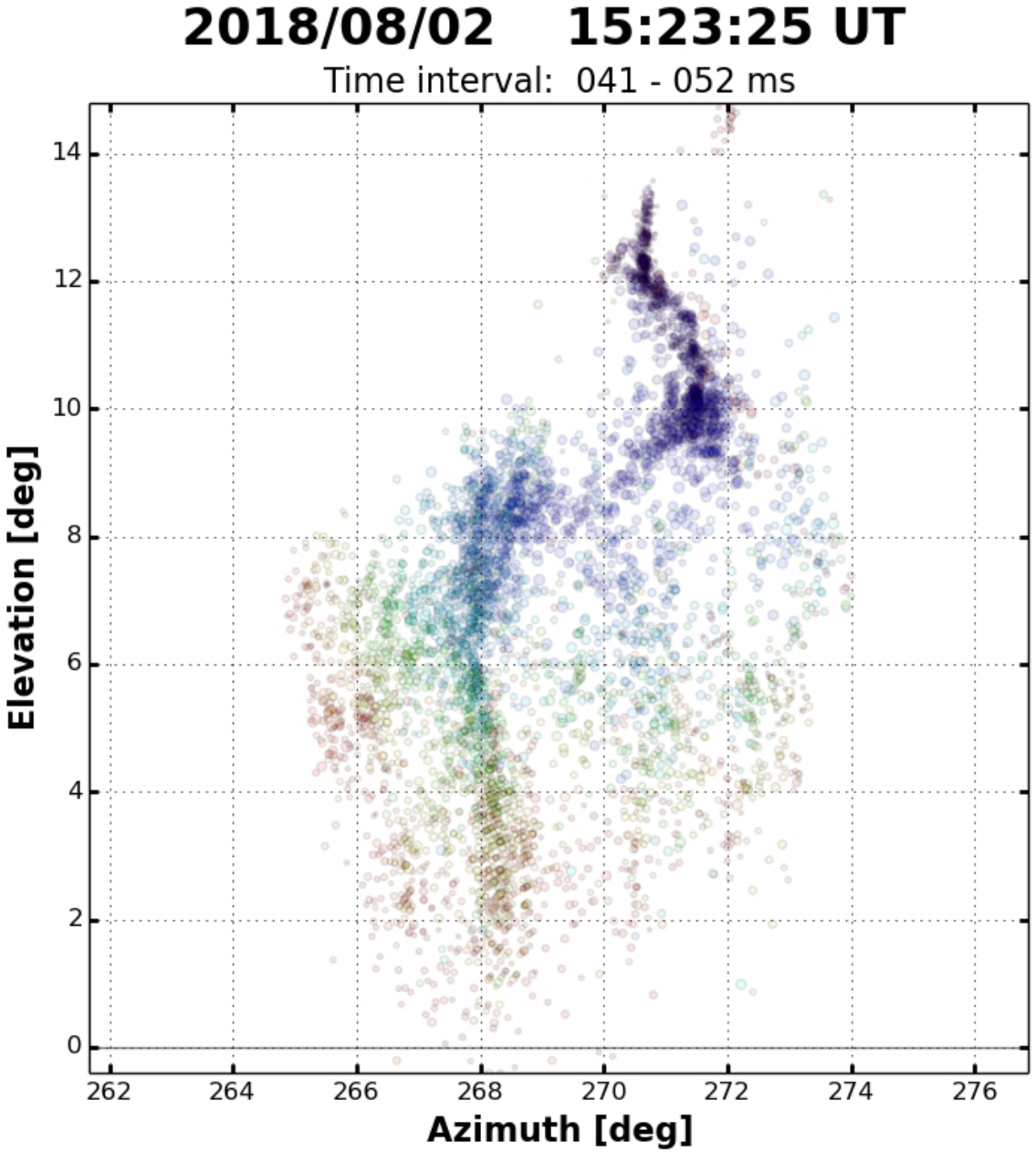
- “Leaders” precede the main flash (return stroke)
- Charge collects in leader tips and strong E fields ionize the air ahead
- Strong E fields also eject electrons and produce bremsstrahlung radiation

Terrestrial Gamma-ray Flashes



- TGFs consist of EM showers driven by ambient E fields
- Electrons are accelerated more than they are slowed by atmospheric interactions, called relativistic runaway electron avalanches (RREA)
- RREA requires energetic seed electrons $\gtrsim$200 keV
  - Cosmic ray secondaries
  - Results suggest thermal runaway electrons accelerated by strong leader E fields

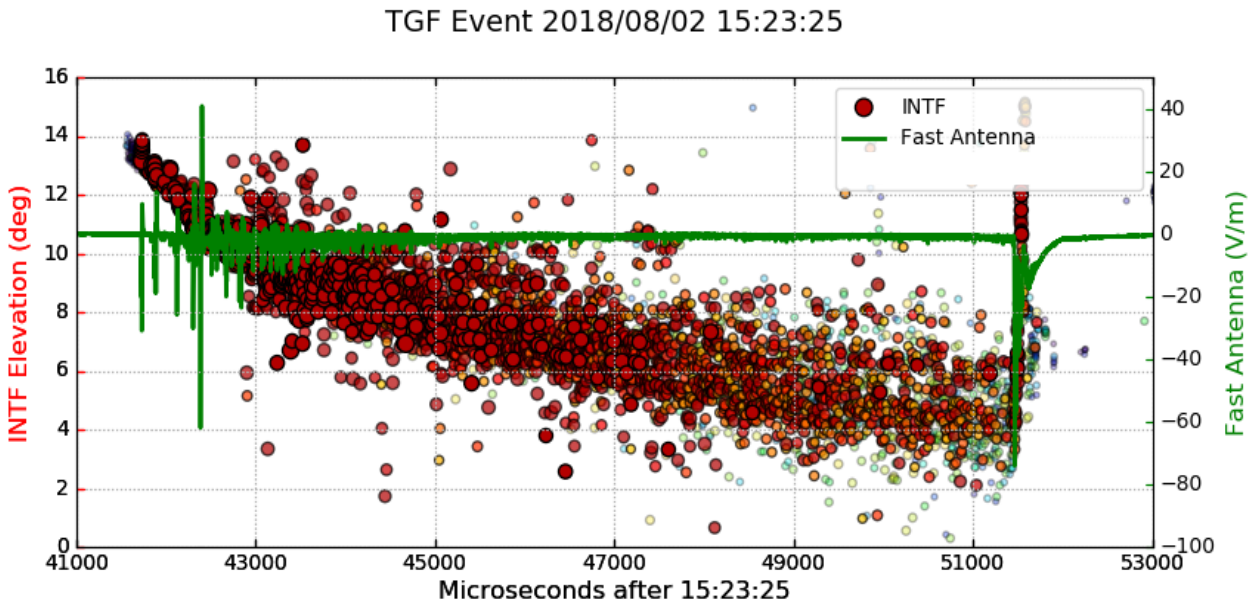
Lightning Instrumentation

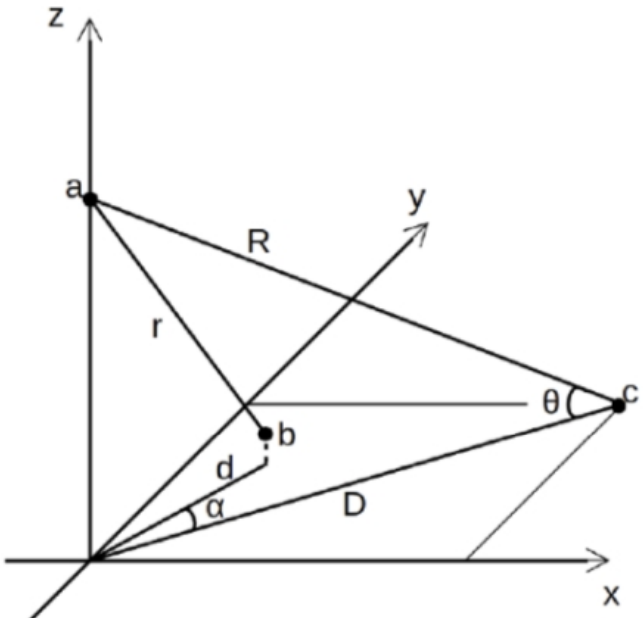


- Broadband Interferometer (INTF)
  - Three 20-80 MHz flat-plate antennas
  - 2D high-resolution reconstruction of lightning sources
- Fast Sferic Sensor (FA)
  - Detects electric field change
  - Identifies substructure: initial breakdown pulses (IBPs)

Detector Cooperation

- Interferometer does not detect the TGF itself
- TASDs do not detect lightning activity



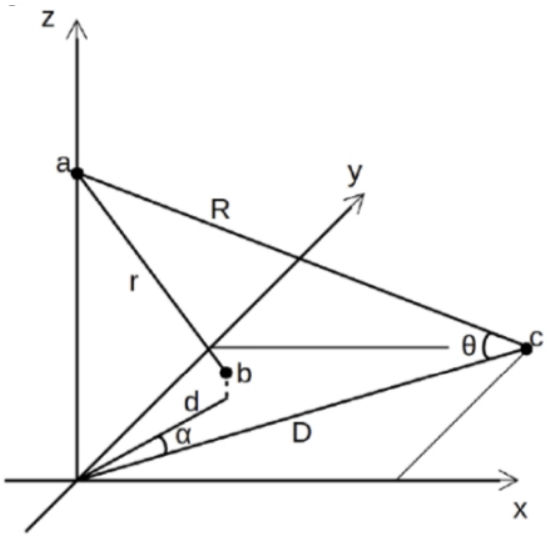


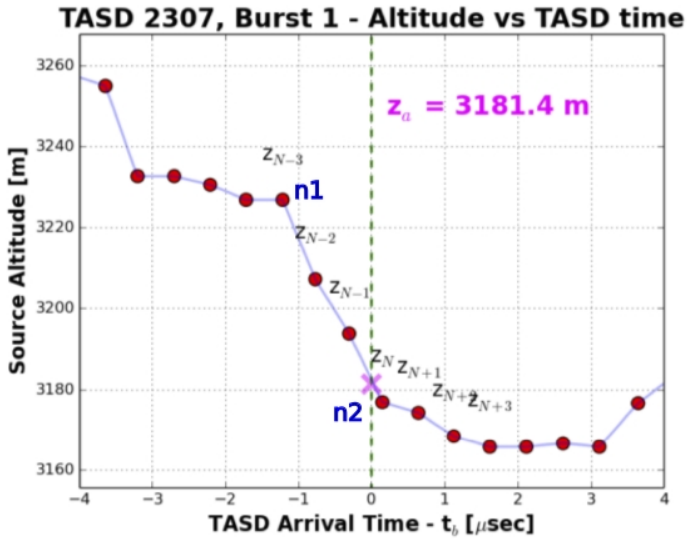
- TGF source altitude depends on TGF onset time z(t)
- Onset time depends on source altitude t(z(t))
- Propagation delays result in relative time differences up to 100 μs
  - Goal is ~1 μs resolution

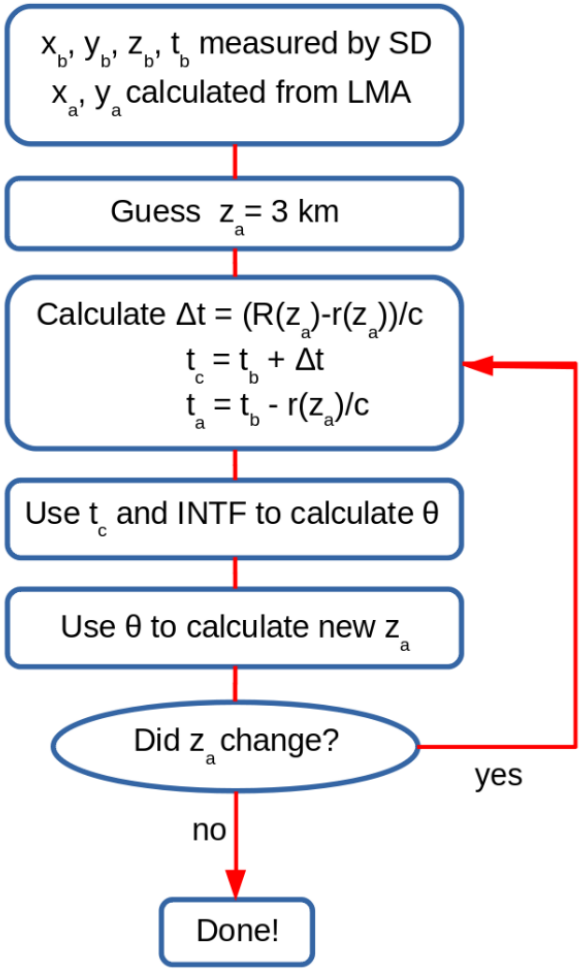
Numerical Analysis

Altitude/time t(z(t)) cannot be inverted analytically – requires numerical solution:

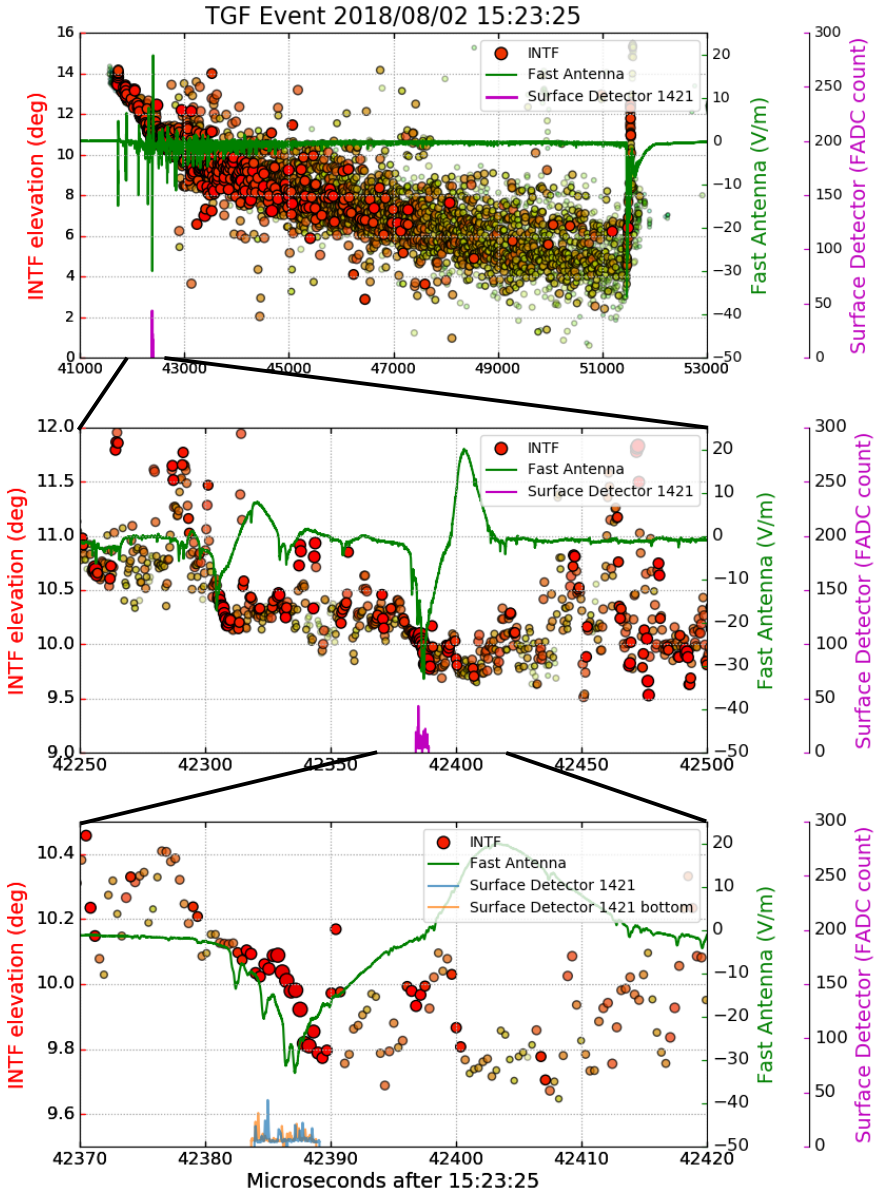
- **Fit** to spherical shower
- **Step** through INTF data points
- **Iterate** over possible solutions







Results



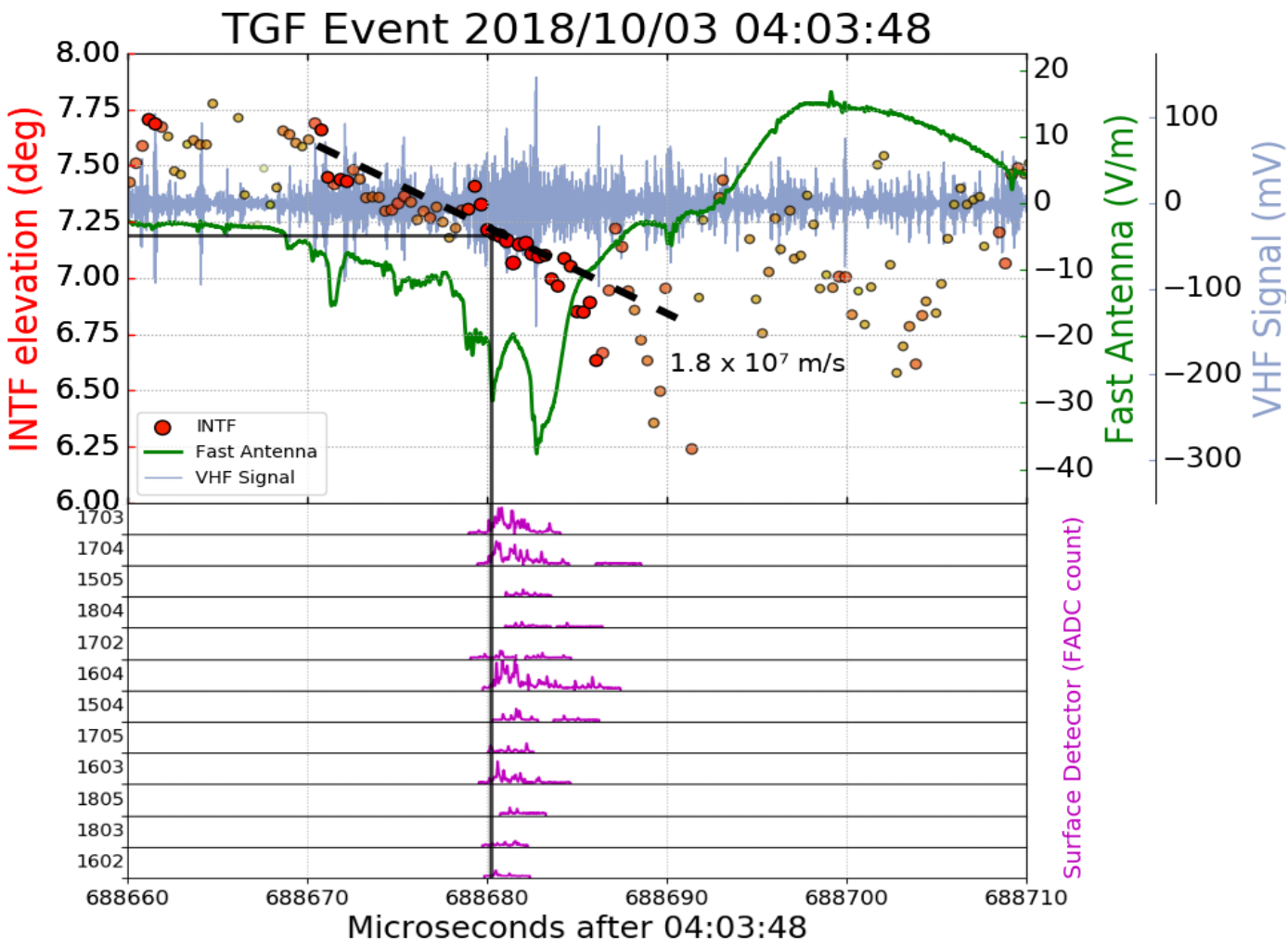
All detector data shifted to account for propagation delays

First ground observations of IBP + TGF!

Time resolution < 1 μs identifies IBP substructure

Results

- Clearly defined TGF onset during the flash's strongest IBP
- Leader propagation speeds up, increased power, more linear
  - Fast negative breakdown
- TGF onset associated with strong sub-pulses



Summary

- The close proximity of detection and careful analysis of downward TGFs at Telescope Array result in timing resolution on the order of a microsecond or better
- Downward TGFs occur during strong IBPs in the initial stages of downward negative lightning
  - Additionally correlated with individual sub-pulses within IBPs during streamer-based fast negative breakdown
- Evidence of individual gamma-rays with energies of at least 6.5 MeV
- Publication on these findings accepted to Journal of Geophysical Research: Atmospheres

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