Field Measurements for Lightning Physics and Meteorology

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Leeman Geophysical
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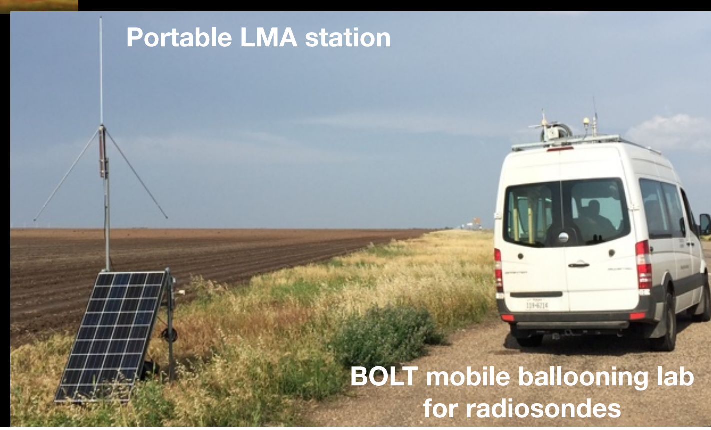
Thunderstorm field measurements

surface and upper air winds, *p*, *T*, *H*
the precipitation and motion inside thunderstorms,
the electric field produced by charged ice particles,
and radio signals produced by lightning

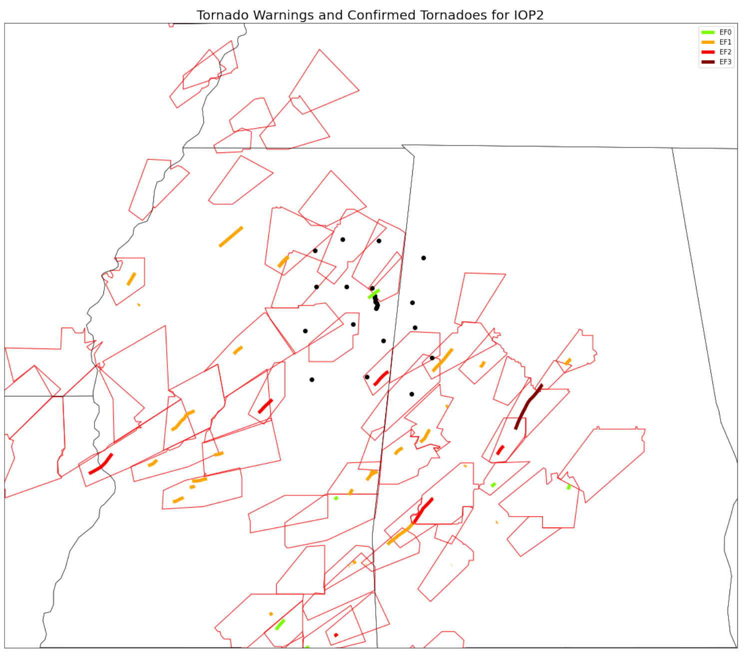


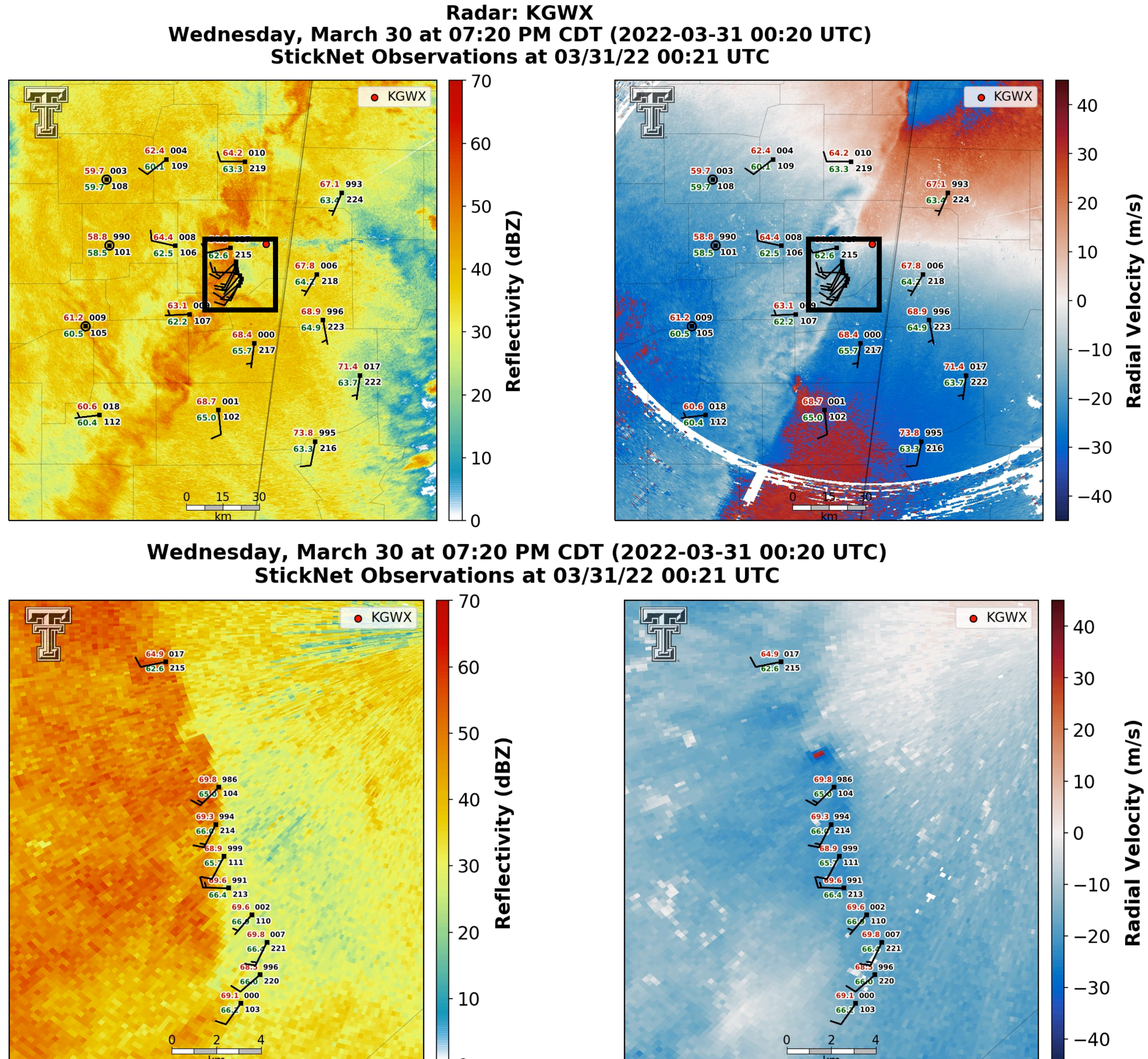
StickNet

Measurements during PERiLS 2022

Tornadoes and temperature gradients in linear convective systems in the southeast US

Figures: Jessie McDonald





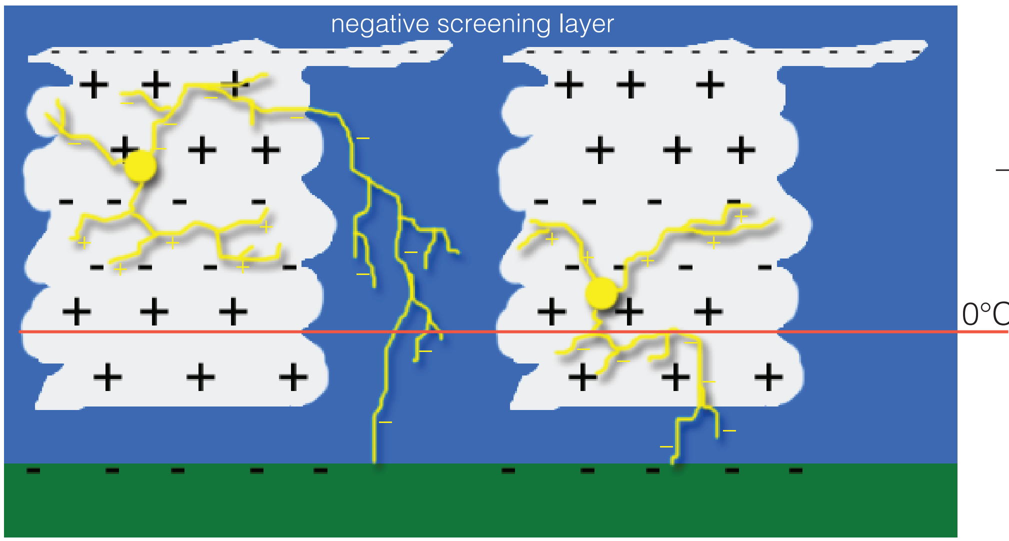
Lightning and storm electricity measurements

Charge motion changes the electric (and magnetic) field

- GPS timing, fast ADCs and computing, and communications advances have made continuous sampling at the time scales of lightning straightforward.
  - Positive channels: 10^4 m/s; Negative channels: 10^5 m/s
  - Fast recoil processes: 10^6 m/s; Return strokes: 10^8 m/s
  - Timing precision needed: 5-10 ns
- Different radio bands emit differently during the discharge
- Pick a band to focus on certain physics (electrostatics, channel stepping, larger-scale current flows along channel)

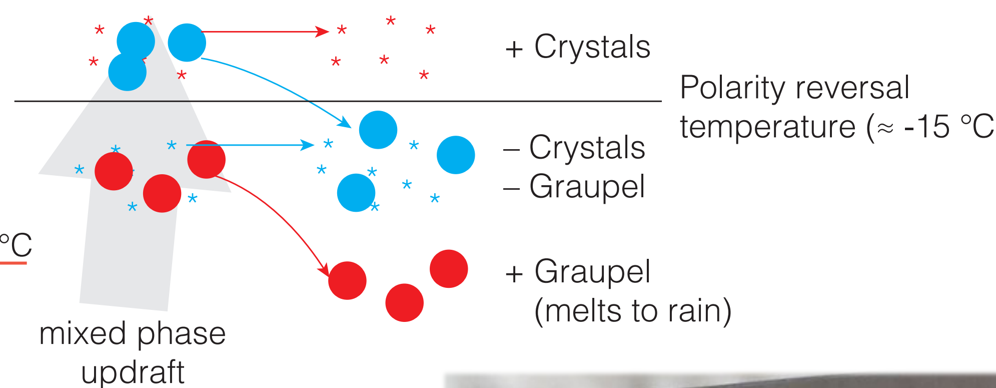
Lightning and electrification

A quick introduction



+ cloud flash (+IC) or bolt-from-blue –CG

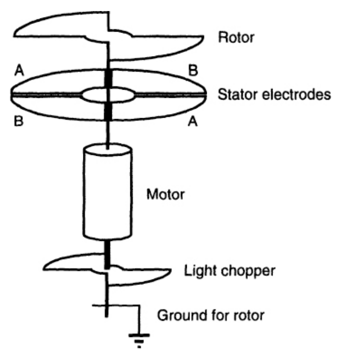
–IC or –CG



- Lightning can be produced between any pair of net charge regions
- Includes both cloud (IC) flashes and Ground (CG) flashes. Polarity of the flash is, by convention, the sign of charge which is lowered.
- 5:1 ratio of cloud flash to ground flash activity

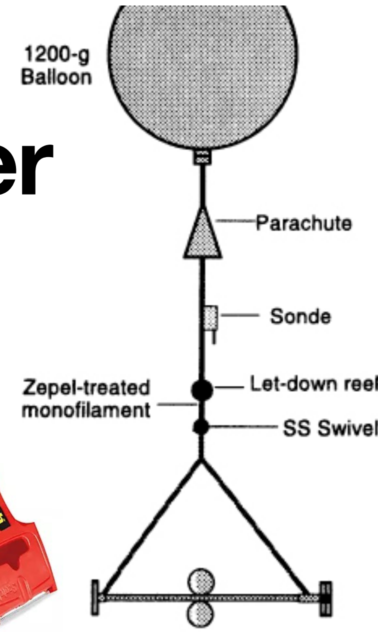
Balloon borne-field meter

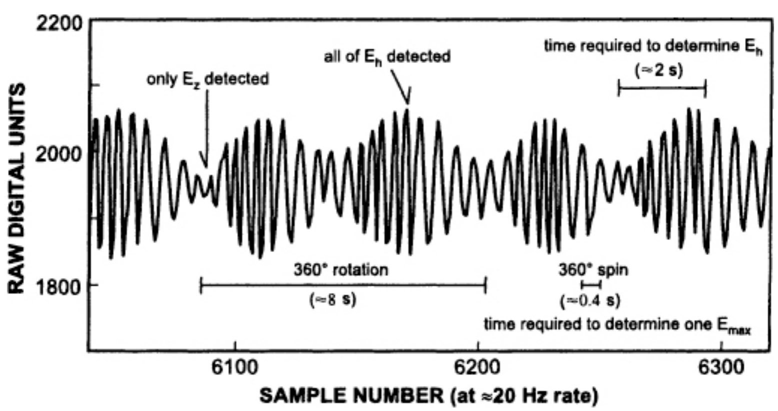
Measures electrostatic vector field



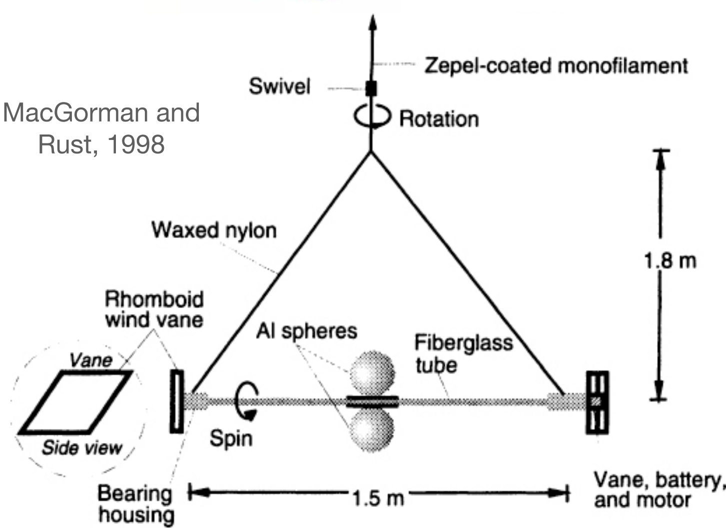
Electric field mill

- Both the ground based field mill (left) and the balloon instrument induce charge by creating an AC signal from the DC field
- Inside spheres: charge amplifier, plus accelerometer and magnetic field reference sinusoids for each axis inside spheres





MacGorman and Rust, 1998



Mobile, High-Wind, Balloon-Launching Apparatus

W. DAVID RUST
NOAA/National Severe Storms Laboratory, Norman, Oklahoma

THOMAS C. MARSHALL
Department of Physics, University of Mississippi, University, Mississippi

28 March 1988 and 27 June 1988

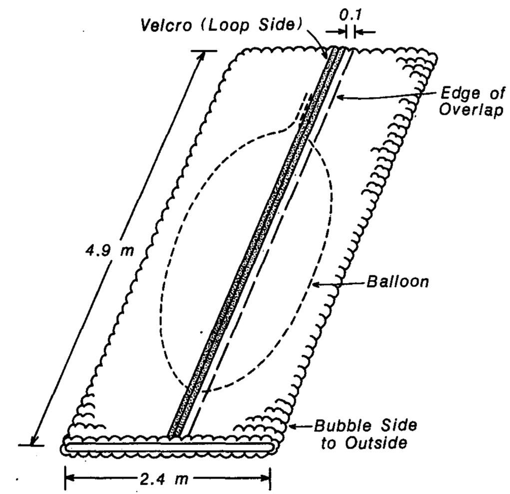
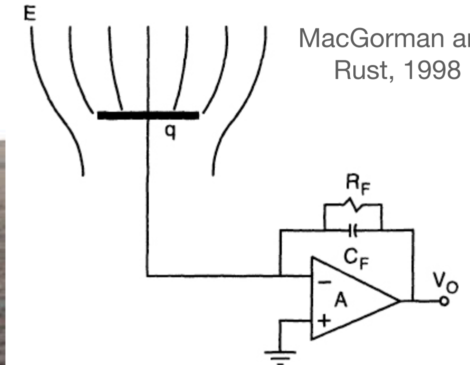


FIG. 1. Sketch showing a launch tube containing an uninflated balloon. Shown are the two lengths of the loop (soft) side of the VELCRO tape, which are sewn to the plastic. The bubble side of the VELCRO tape is to the outside the launch tube; the smooth to the inside. The overlap is to keep debris stuck on the hook side of the VELCRO from puncturing the balloon. Dimensions are for a launch tube for a 1200 gm balloon.

Electric field change antennas

A charge transducer



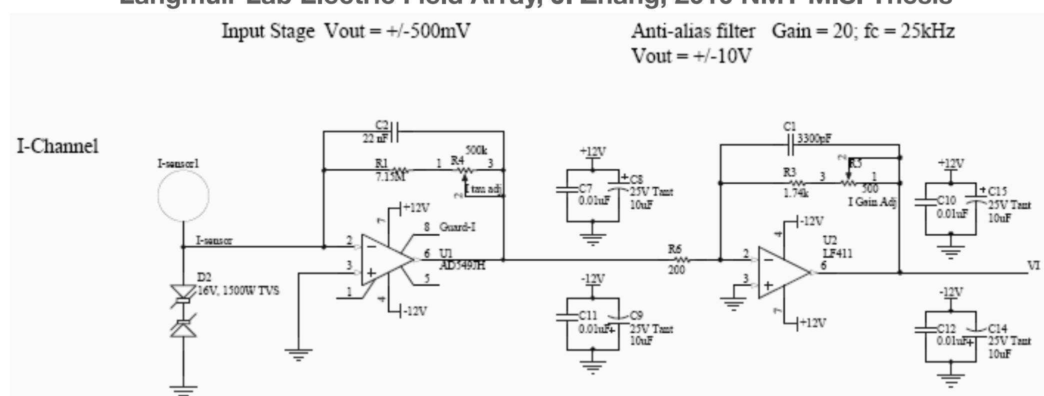
MacGorman and Rust, 1998

- Electric field change induces a charge on a metal plate
- Output voltage is directly proportional to electric field change
- Charge is collected and amplified by an inverting op-amp integrator with an additional Rf in parallel with Cf. We call this a charge amplifier.
- This acts as high pass filter, and keeps the observations within range of the ADC. Rf bleeds off charge with an exponential decay time constant of RC.
- “Slow” antennas have a longer RC ~ 10 s (0.16 Hz corner) while “fast” antennas have RC ~ 1 ms (160 Hz corner) constant. Slow antennas actually have a wider passband than fast antennas, and so would be preferable, but are limited by the gain-bandwidth product.

All three channels:
RC =150 ms

Max E:
0.68, 18, 500 kV/m

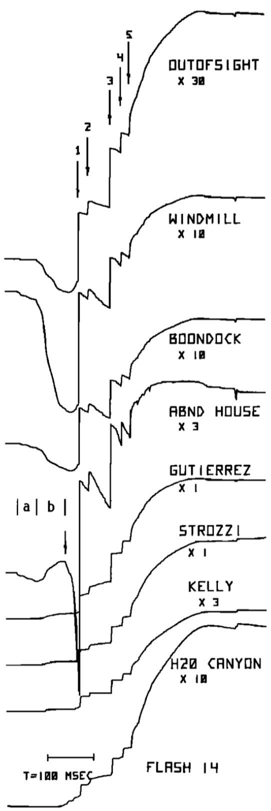
Langmuir Lab Electric Field Array, J. Zhang, 2010 NMT M.S. Thesis



https://www.electronics-tutorials.ws/opamp/opamp_6.html

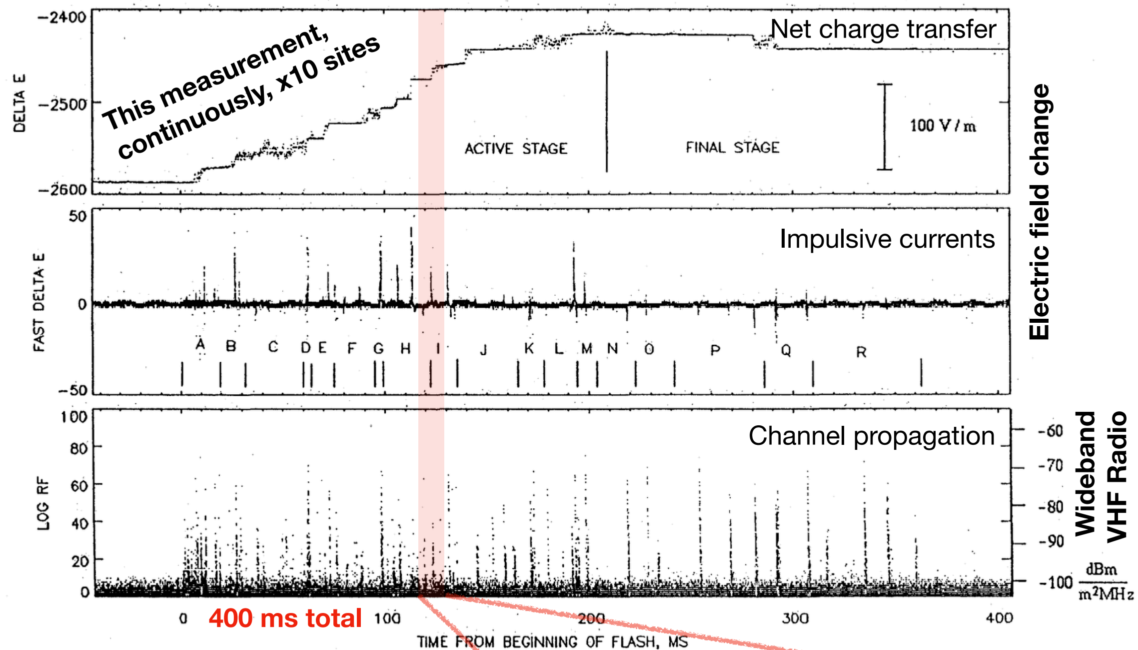
Electric field change measurements

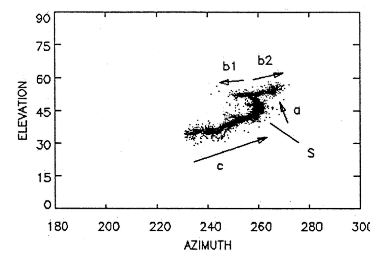
characterize discharge physics in detail



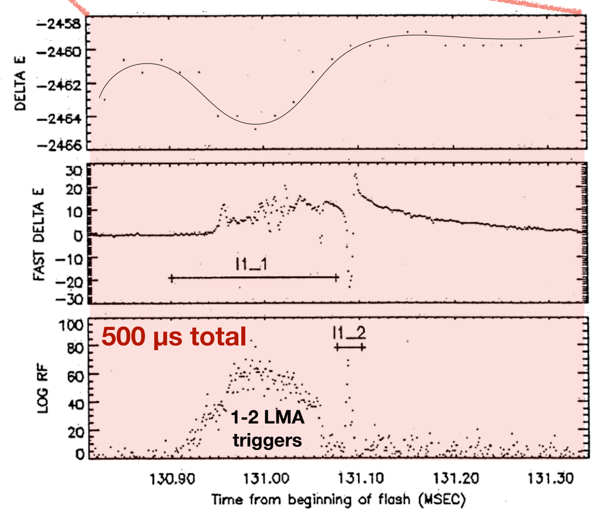
Krehbiel et al. (1979)

- Understanding how charge moves in the sky has, since the 1960s, relied on electric field change measurements.
    - Digitizes output of a charge amplifier connected to a flat plate.
    - Slow (10 s) and fast (1 ms) decay time constants on charge amplifier: **slow and fast antennas**.
    - “Medium” antenna: 100 ms time constant (newer HAMMA systems by Bitzer et al.
    - Current science: 10 MHz sample rate.
    - Still deployed to do validation of classification and deep study of individual discharges
    - Can also geolocate peaks of pulses
- Newer VHF mapping systems provide essential context.
    - Time of arrival - peak pulse every 80 μs, sampled at 25 Msps, 6 MHz bandwidth
    - Interferometry: 180 Msps, 10s of MHz bandwidth

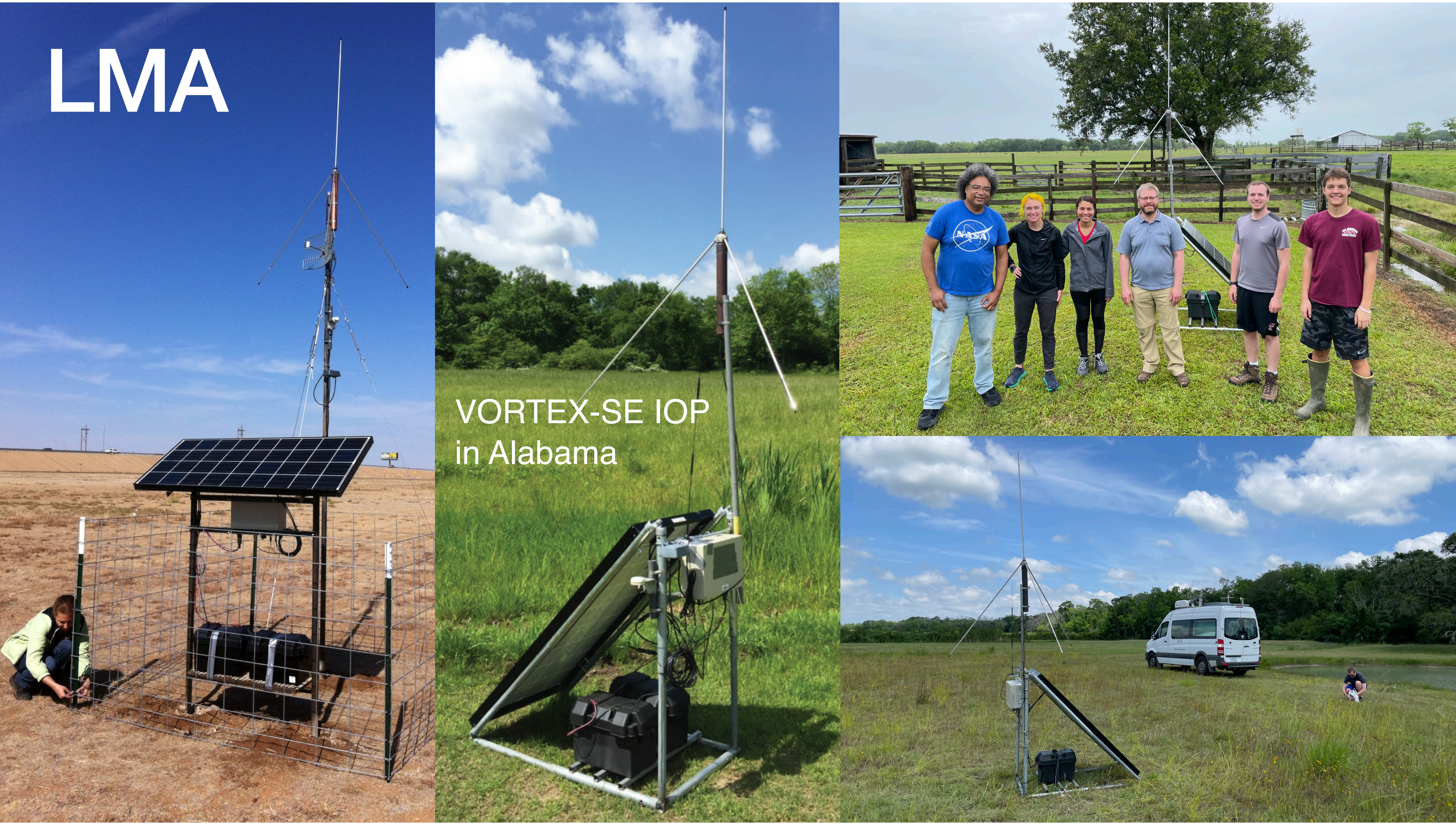




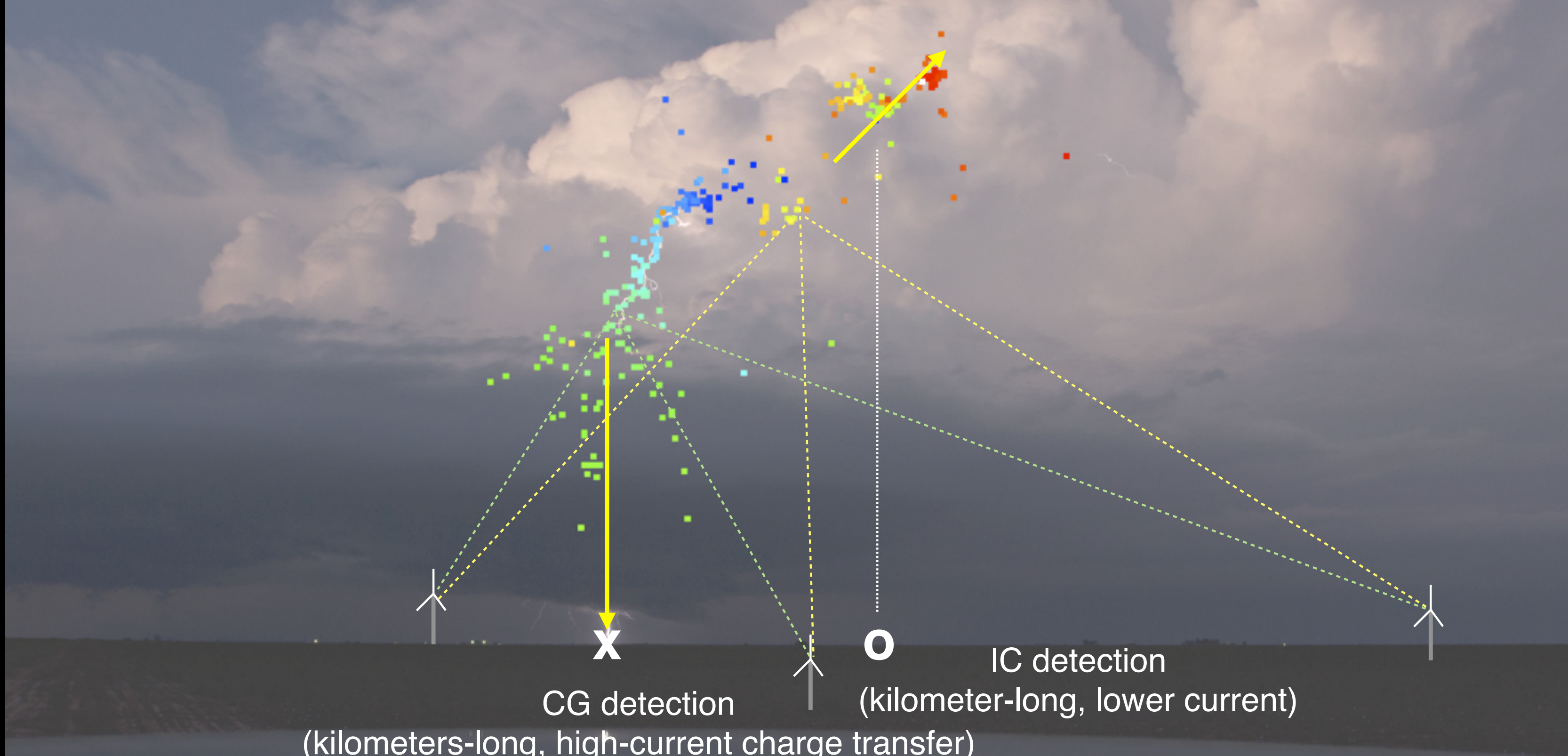
Interferometer (LMA-like)



Shao and Krehbiel (1996, J. Geophys. Res.)


LMA
VORTEX-SE IOP
in Alabama

Radio frequency lightning detection

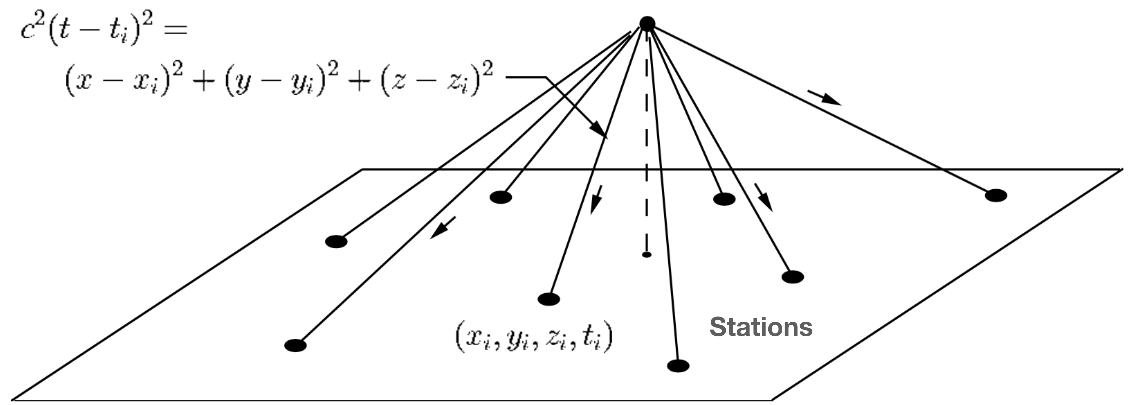


Like all lightning, this bolt from the blue CG flash creates a broadband radio signal (a sferic). VLF/LF radiation is used to detect large peak currents(1-500 kA) made by ground (CG) and cloud (IC) strokes. VHF also emitted (-10 to 40 dBW) by each step in channel development; measured by a Lightning Mapping Array.

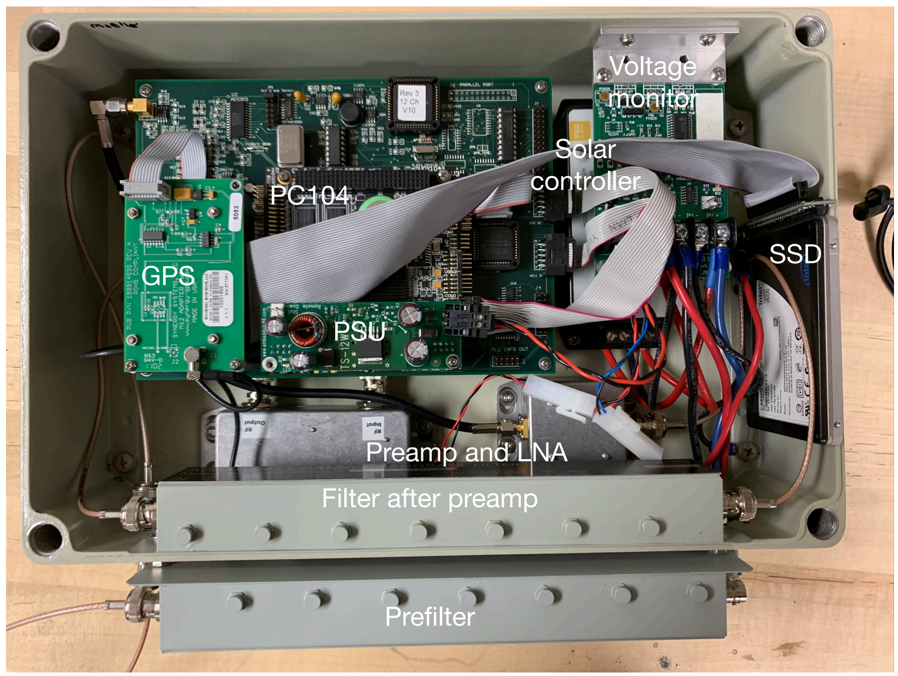
Time of arrival

e.g. VHF source mapping

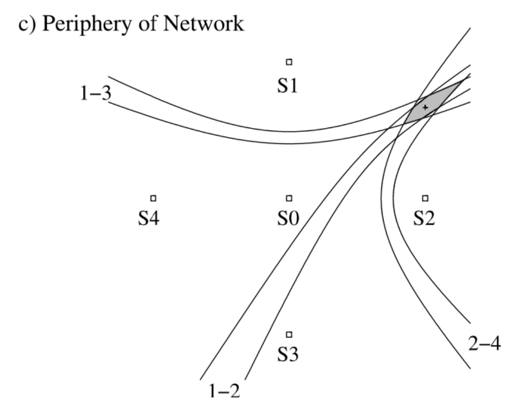
- **GPS timing** enabled continuous mapping of VHF in ~1998. Digitizer sync'd to PPS at each station, **20-70 ns error.**
- LMA: 60-66 MHz VHF band, 25 MHz ADC, saves time of peak pulse in 80μs window. Linux single board computer (PC104). **Processes solutions in real time on a single core of a desktop PC.** 100 km 3D mapping, 300 km 2D mapping.
- Very **low noise floor** - electronics and solar charger **inside a sealed metal box**; capacitive filter on power connector, metal cap for ethernet jack.



Thomas et al. 2004, JGR



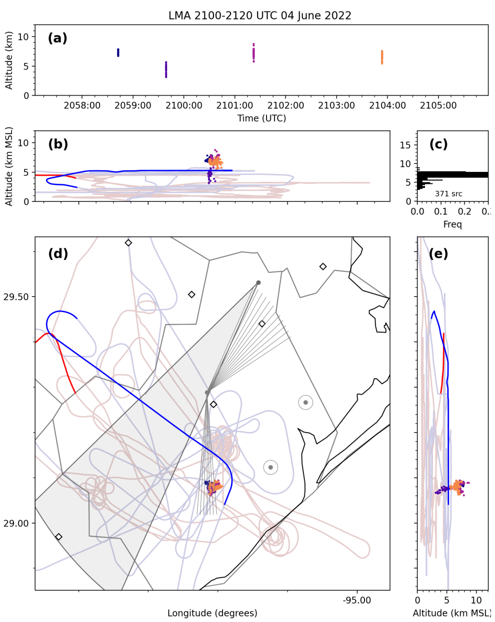
Pairs of stations make hyperbolas, indicated here with timing error



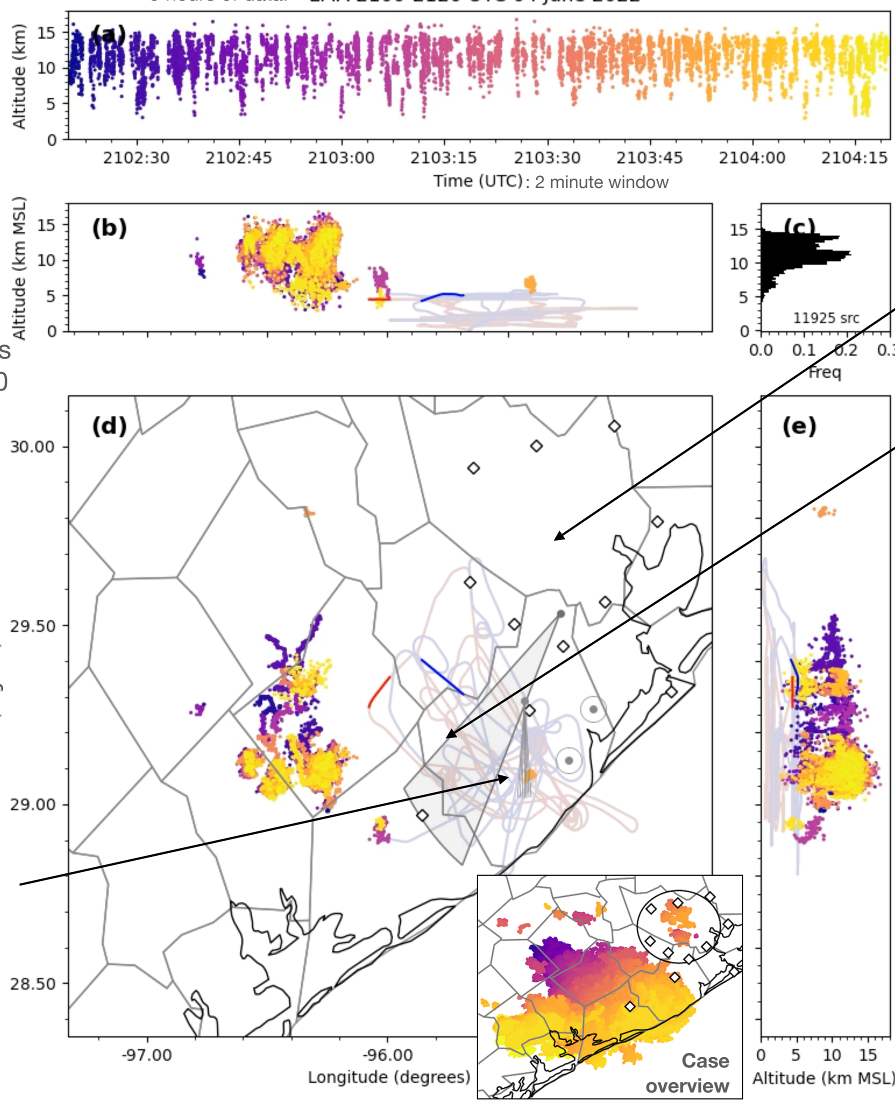
Houston Lightning Mapping Array

Overview, including ESCAPE observations

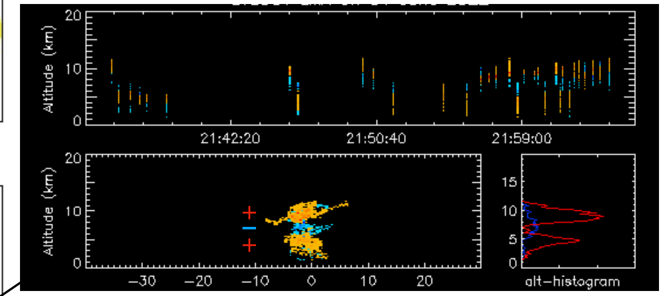
1. Isolated, barely electrified sea-breeze storm with four flashes. Convair and Lear sampled representative cloud microphysics before and after these flashes, and PX1000 captured RHIs



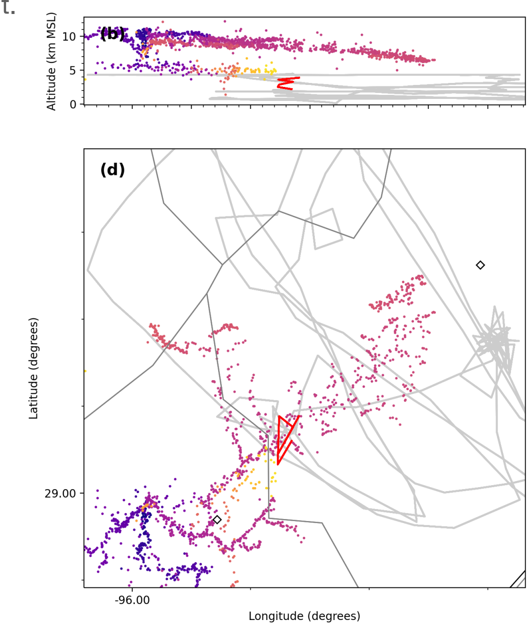
5 hours of data:



2. Normal polarity charge structure in cell in Houston



3. Many extensive anvil level discharges extended eastward from an MCS, with negative charge layer microphysics sampled by Convair just prior to spiral descent.

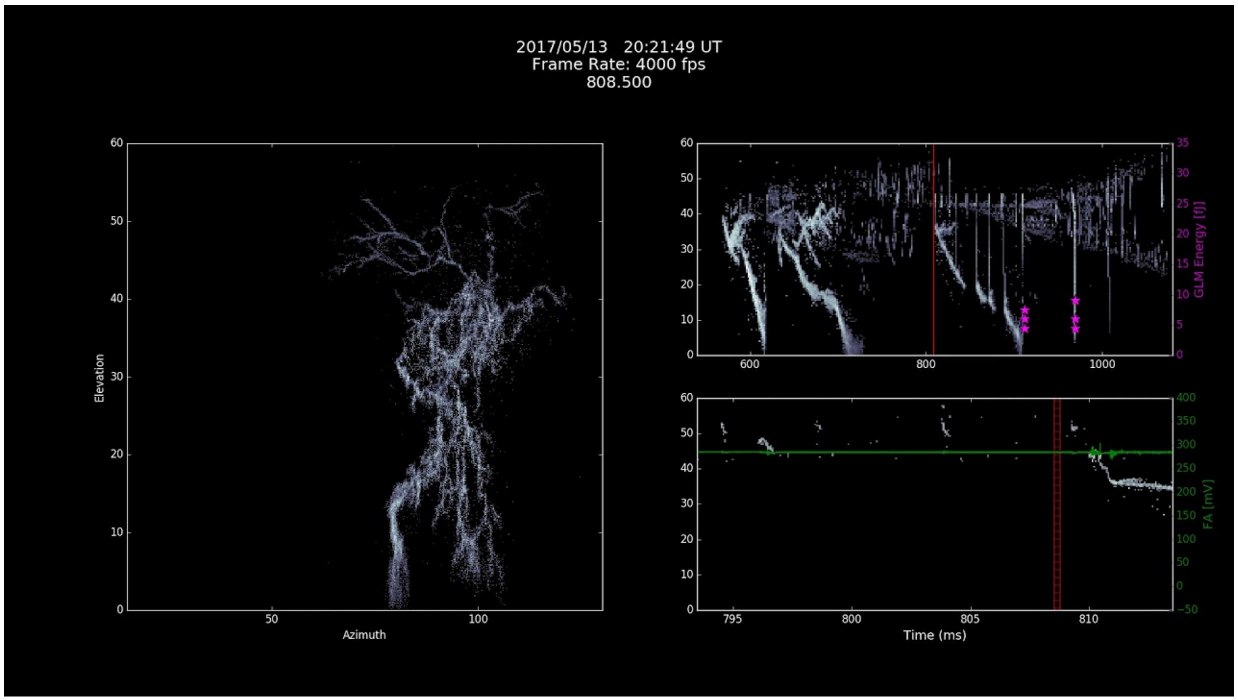


Interferometry

Interferometry

LANL interferometer,
20-80 MHz band **sampled at 190 MHz, 14 bit**
Reuses several polarized, repurposed LWA antennas from radio astronomy

Below: 50 μs total data in a 2x2° field of view during initial breakdown



New Mexico Tech Interferometer (Stock et al. 2014, JGR)
80 MHz bandwidth sampled at 180 MHz, 16 bit
Uses several cake pans, ~10m baseline

Above: video of a cloud-to-ground lightning discharge.

Shao et al. 2020, 10.1029/2019JD032273

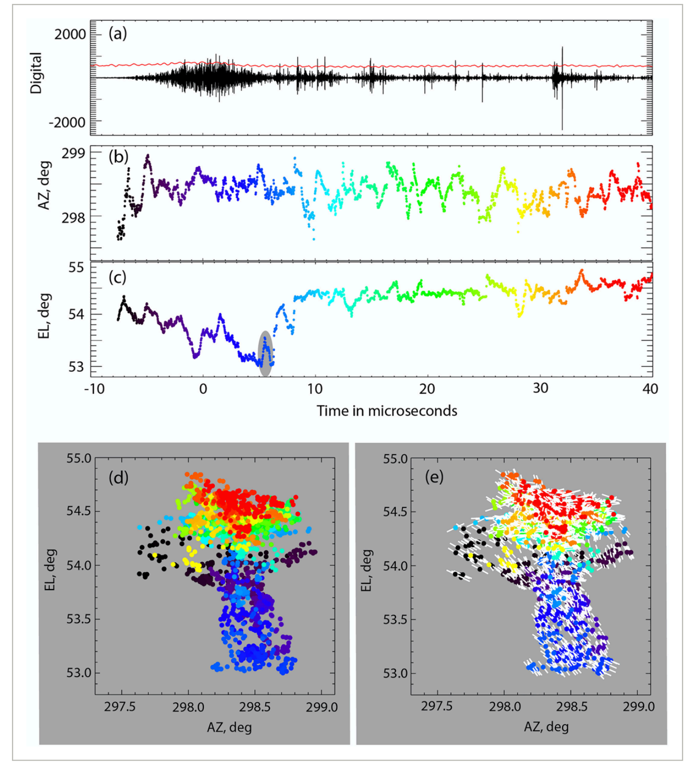


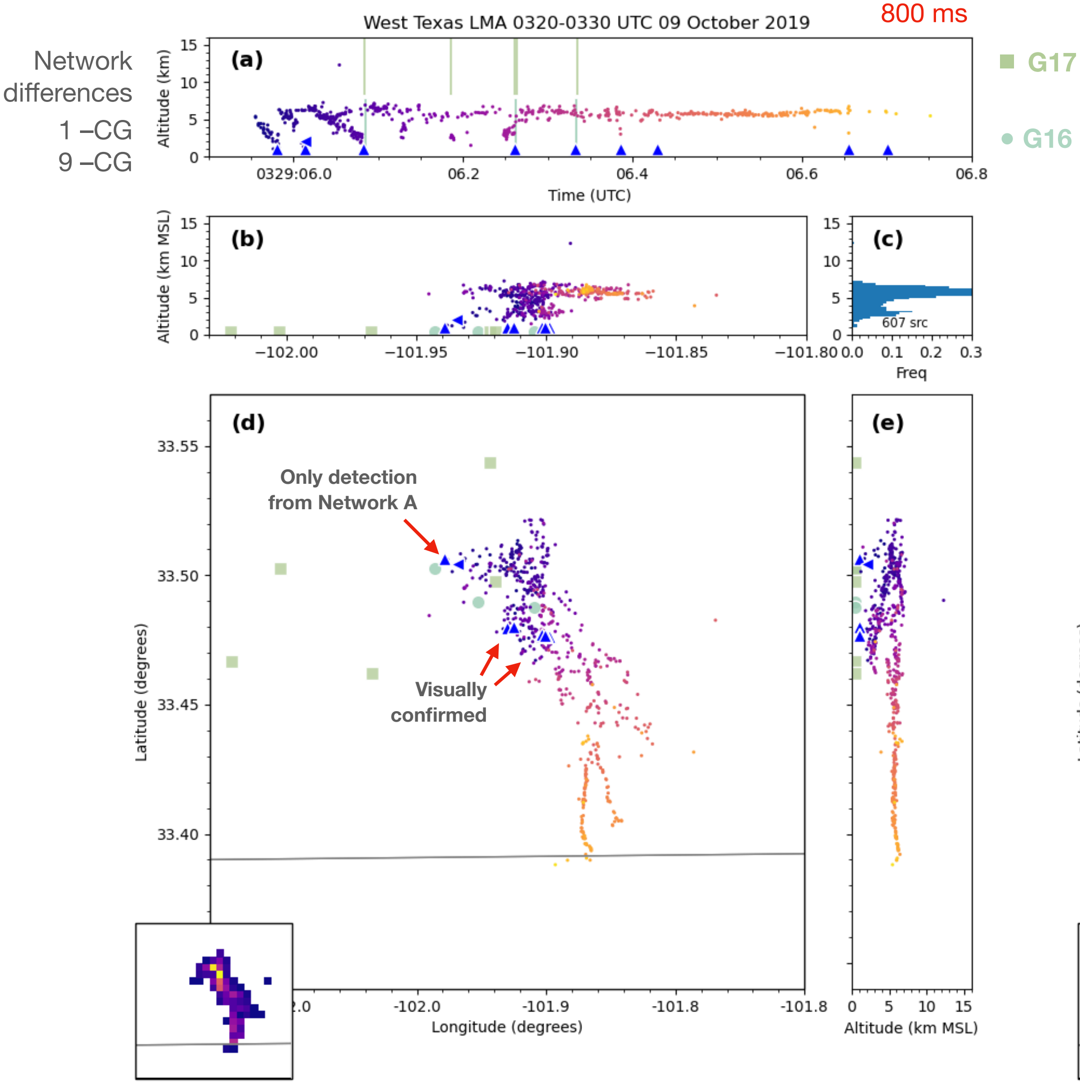
Figure 7 Open in figure viewer | PowerPoint

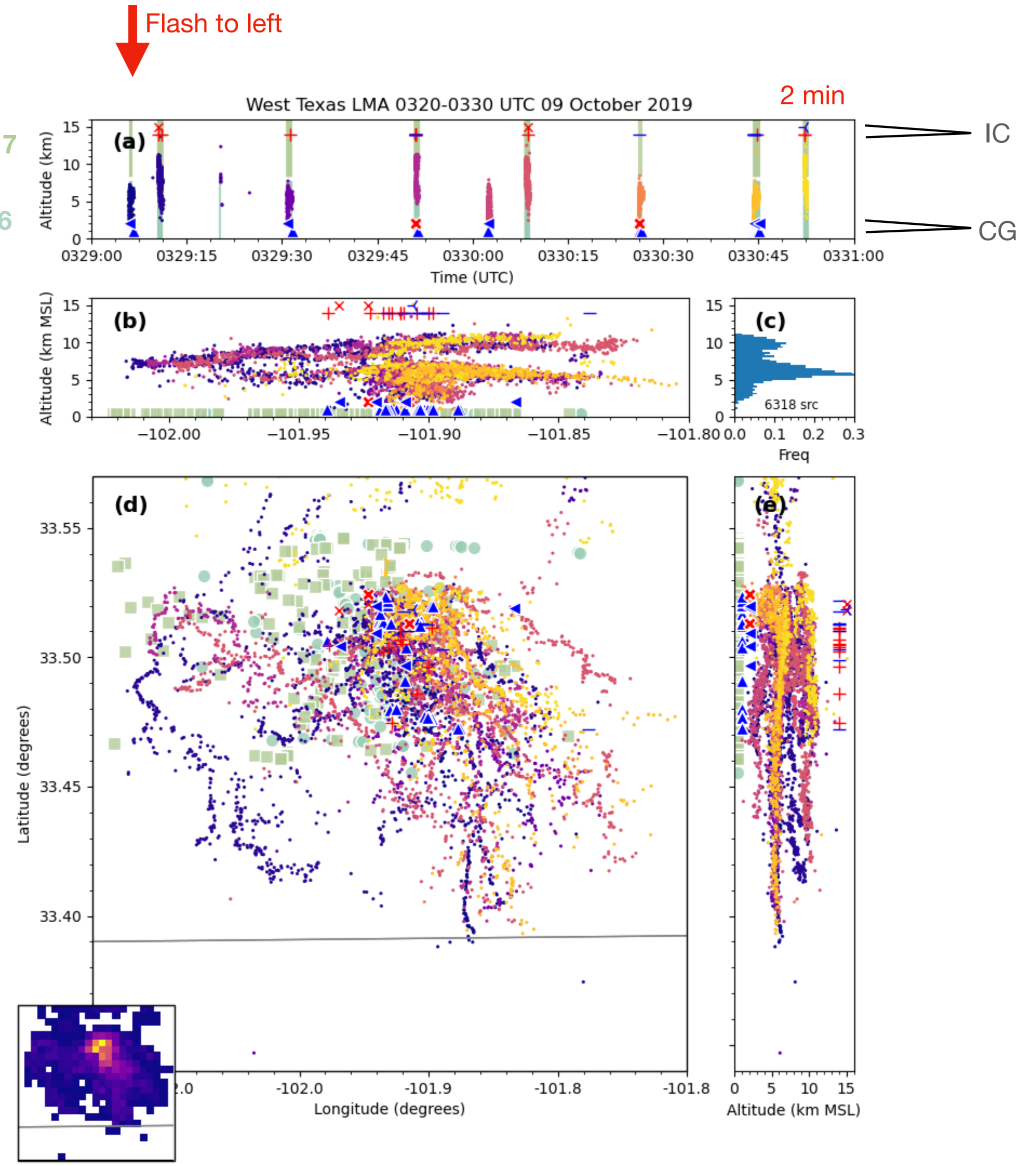
Observations including the initial FPB and following negative breakdown up to 40 μs. (a) RF time waveform. (b, c) Time-dependent AZ, EL. (d) AZ-EL plot. (e) AZ-EL plot with polarization orientation.

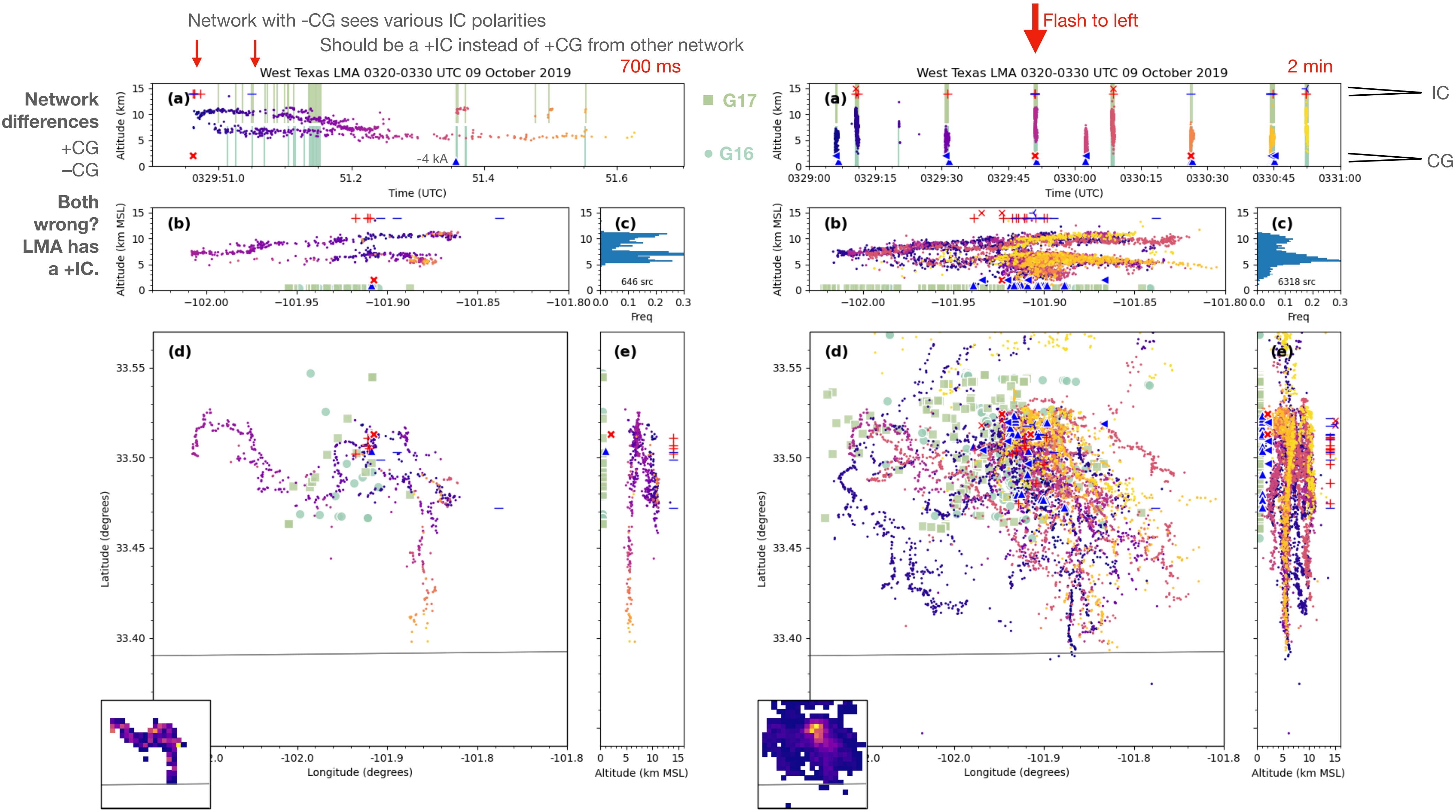
Summary

- Technological advancement continues to open new frontiers in measurement
  - Computers are really fast
  - GPS timing is amazingly precise
- Common household goods are quite useful for scientific instruments
- After you have a working instrument, make an investment in smoothing logistics and reliability during field deployments.
  - Iterate and don’t over-think

Large flashes, some making ground strikes, near Lubbock







Network with -CG sees various IC polarities
Should be a +IC instead of +CG from other network
Flash to left
West Texas LMA 0320-0330 UTC 09 October 2019
700 ms
2 min
Network differences
+CG
–CG
Both wrong? LMA has a +IC.
G17
G16
IC
CG
-4 kA
Altitude (km)
Time (UTC)
Altitude (km MSL)
Freq
646 src
6318 src
Latitude (degrees)
Longitude (degrees)