Broadband radio interferometer observations of fast electrical processes in thunderstorms

Julia N. Tilles¹, Ningyu Liu¹, Mark A. Stanley², Paul R. Krehbiel², William Rison², Joseph R. Dwyer¹, Robert Brown³, Jennifer Wilson³

¹ Department of Physics and Space Science Center, University of New Hampshire, Durham, NH
² Langmuir Laboratory for Atmospheric Research, New Mexico Tech, Socorro, NM
³ Kennedy Space Center, FL
Radio array
Radio array

Bandwidth: \( \sim 20-80 \text{ MHz} \)
Baselines: 100 m

AlazarTech digitizer (ATS9462)
→ 2-channel
→ 180 MSps
→ 16 bits
→ Triggered recording on strong VHF

*** Records raw (5.5 ns) voltage waveforms ***
Radio array

HF/VHF (~20-80 MHz) sensor

Three sensors used in interferometry

\[
\frac{dE}{dt} = - R_{out} A \varepsilon_0 \frac{dE}{dt}
\]
Radio array

“Fast” antenna (~3 kHz – 3 MHz)

One sensor used for modelling electric current.
Radio array

~160 MB per -50/+50 ms trigger (4 channels at 180 MSps, 16 bits).
~60 TB per year.
Source characteristics – leaders

→ Hot, very conductive, highly ionized plasma filaments (Walker and Christian, 2014, ICAE).
→ Optically bright.
→ Typical propagation speeds of $10^4$ to $10^5$ m/s.
Source characteristics – streamers

→ Cold filamentary plasma discharge waves.
→ Not as conductive or ionized as leaders.
→ Propagation speeds up to $10^7$ m/s.
→ HF/VHF bright.

Petersen and Beasley, 2013, *JGR*
Source characteristics – streamers

- Cold filamentary plasma discharge waves.
- Not as conductive or ionized as leaders.
- Propagation speeds up to $10^7$ m/s.
- HF/VHF bright.

Petersen et al., 2008, *JGR*
Source characteristics – streamers

- Cold filamentary plasma discharge waves.
- Not as conductive or ionized as leaders.
- Propagation speeds up to $10^7$ m/s.
- HF/VHF bright.

Source characteristics – TGFs

- High energy (>1 MeV) photons, produced by runaway electrons, that can escape Earth’s atmosphere to reach spacecraft in orbit (Fishman et al., 1994).
- Produced during upward leader propagation in thunderstorms (Cummer, et al, 2015, GRL).
Interferometry
Interferometry
Radio interferometer observations of fast processes in thunderstorms

Interferometry

- $\Delta A_z=1^\circ$
- $\Delta A_z=1.5^\circ$
- $\Delta A_z=2^\circ$
- $\Delta A_z=2.5^\circ$

- $\Delta E_\ell=3^\circ$
- $\Delta E_\ell=4^\circ$
- $\Delta E_\ell=5^\circ$
- $\Delta E_\ell=6^\circ$

Elevation angle ($^\circ$)

Azimuth angle ($^\circ$)

$k$: (50.49, 23.07)  $l$: (50.74, 23.01)  $m$: (50.48, 23.49)  $n$: (52.68, 23.40)

$p$: (50.00, 24.56)  $q$: (50.00, 25.09)  $r$: (50.19, 27.00)  $s$: (50.40, 28.63)
Interferometry
Interferometry
Interferometry
Results – lightning initiation

→ Narrow bipolar event (NBE) study with interferometer (Rison et al., 2016, Nat. Comms.).
→ NBEs generated by fast ($10^7 - 10^8$ m/s) positive breakdown, tens of kA.
→ Fast positive breakdown may initiate all lightning.
→ Agreed with lightning initiation theories involving positive streamers.
Results – lightning initiation

→ NBE study with interferometer (Tilles et al., 2019, Nat. Comms.).

![Diagram showing lightning parameters and downward current](image)
Results – lightning initiation

- NBE study with interferometer (Tilles et al., 2019, Nat. Comms.).
- NBEs generated by fast \((10^7 - 10^8 \text{ m/s})\) negative breakdown, tens of kA.
- Negative streamers may initiate some lightning.
- In disagreement with lightning initiation theories involving positive streamers.
Fast antenna and electric current

\[ E_z(r, \phi, z = 0, t) = \frac{1}{2\pi \epsilon_0} \left[ \int_{H_B}^{H_T} \frac{2z' - r^2}{R^5} \int_0^t i \left( z', t' - \frac{R}{c} \right) dt' dz' \right. \]
\[ + \int_{H_B}^{H_T} \frac{2z'^2 - r^2}{cR^4} i \left( z', t - \frac{R}{c} \right) dz' \]
\[ - \int_{H_B}^{H_T} \frac{r^2}{c^2 R^3} \frac{\partial}{\partial t} i \left( z', t - \frac{R}{c} \right) dz' \]

Uman, 2001, *The Lightning Discharge*

→ Current moment
→ Charge moment change
→ Current polarity
→ Current rise e-folding time
→ Peak current