# Broadband radio interferometer observations of fast electrical processes in thunderstorms

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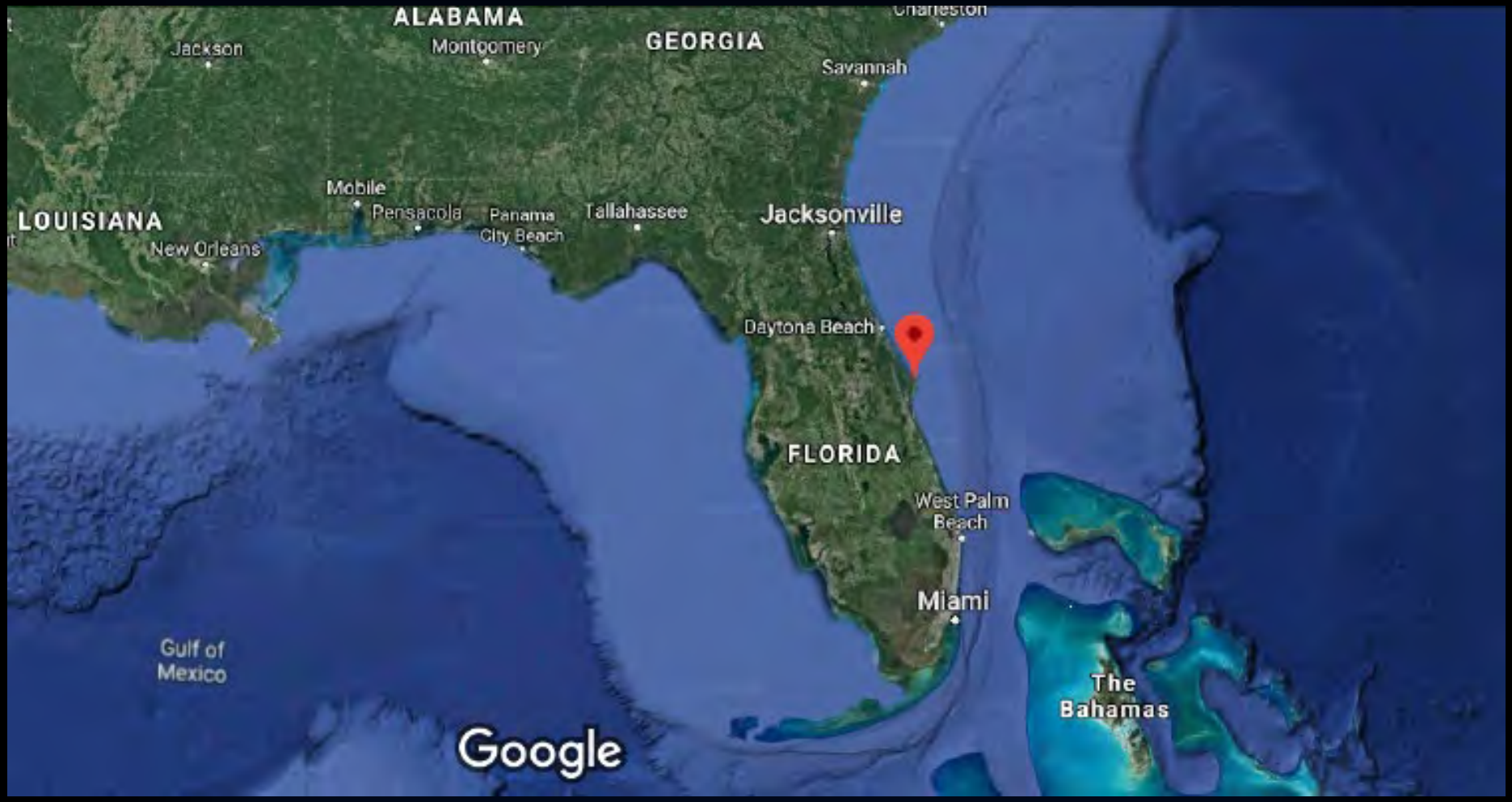
[3] Kennedy Space Center, FL

# Radio array




200 km



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# Radio array


Bandwidth: ~20-80 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 ***

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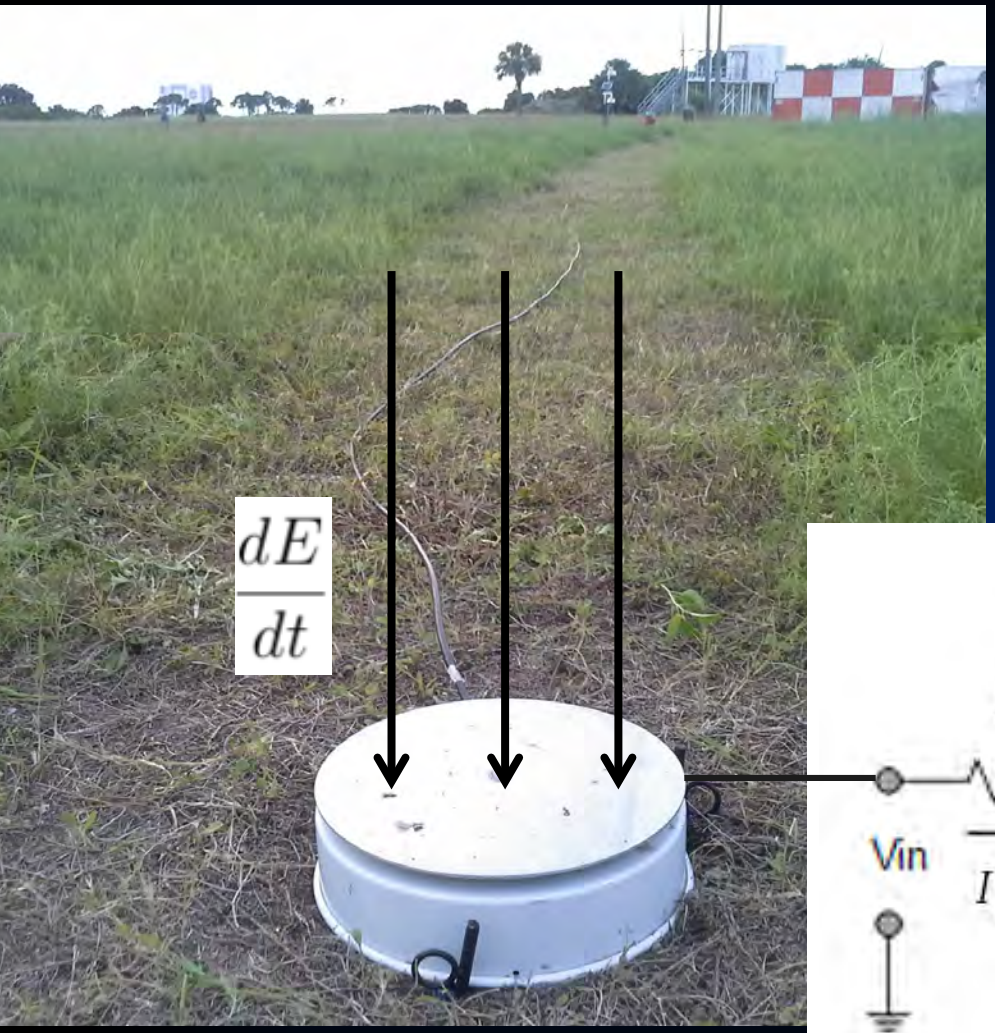
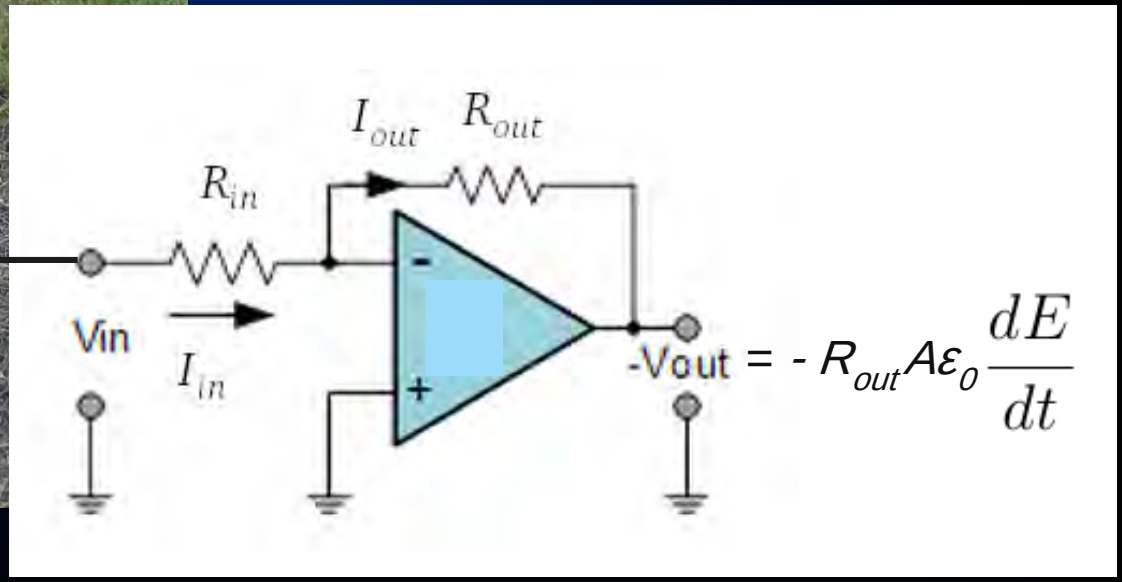
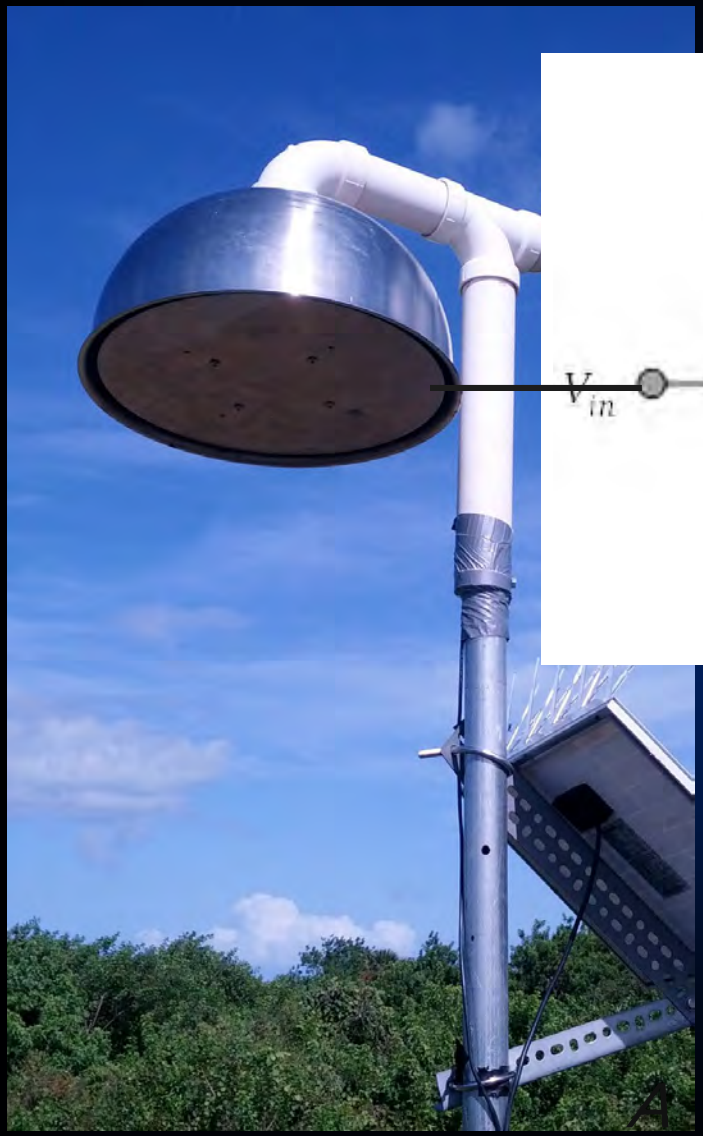


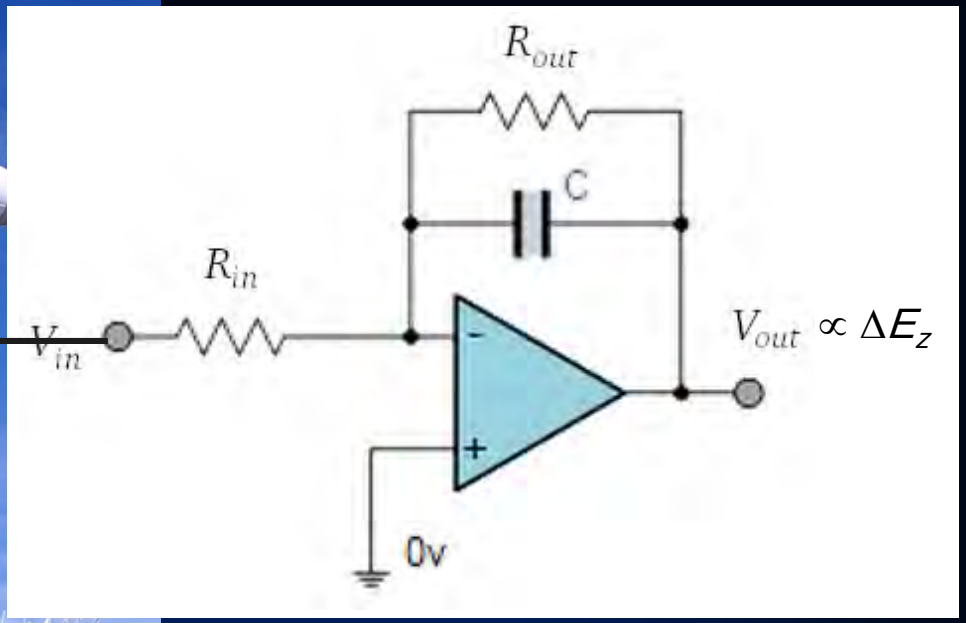

HF/VHF (~20-80 MHz) sensor

Three sensors used in interferometry



# Radio array

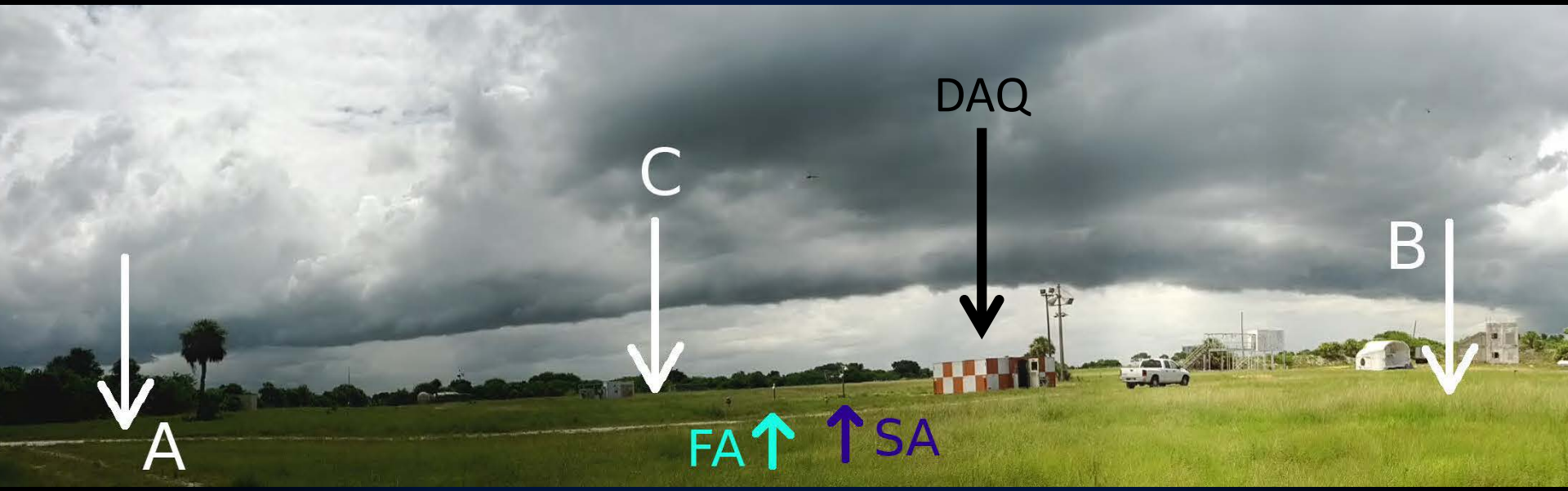





"Fast" antenna (~3 kHz – 3 MHz)

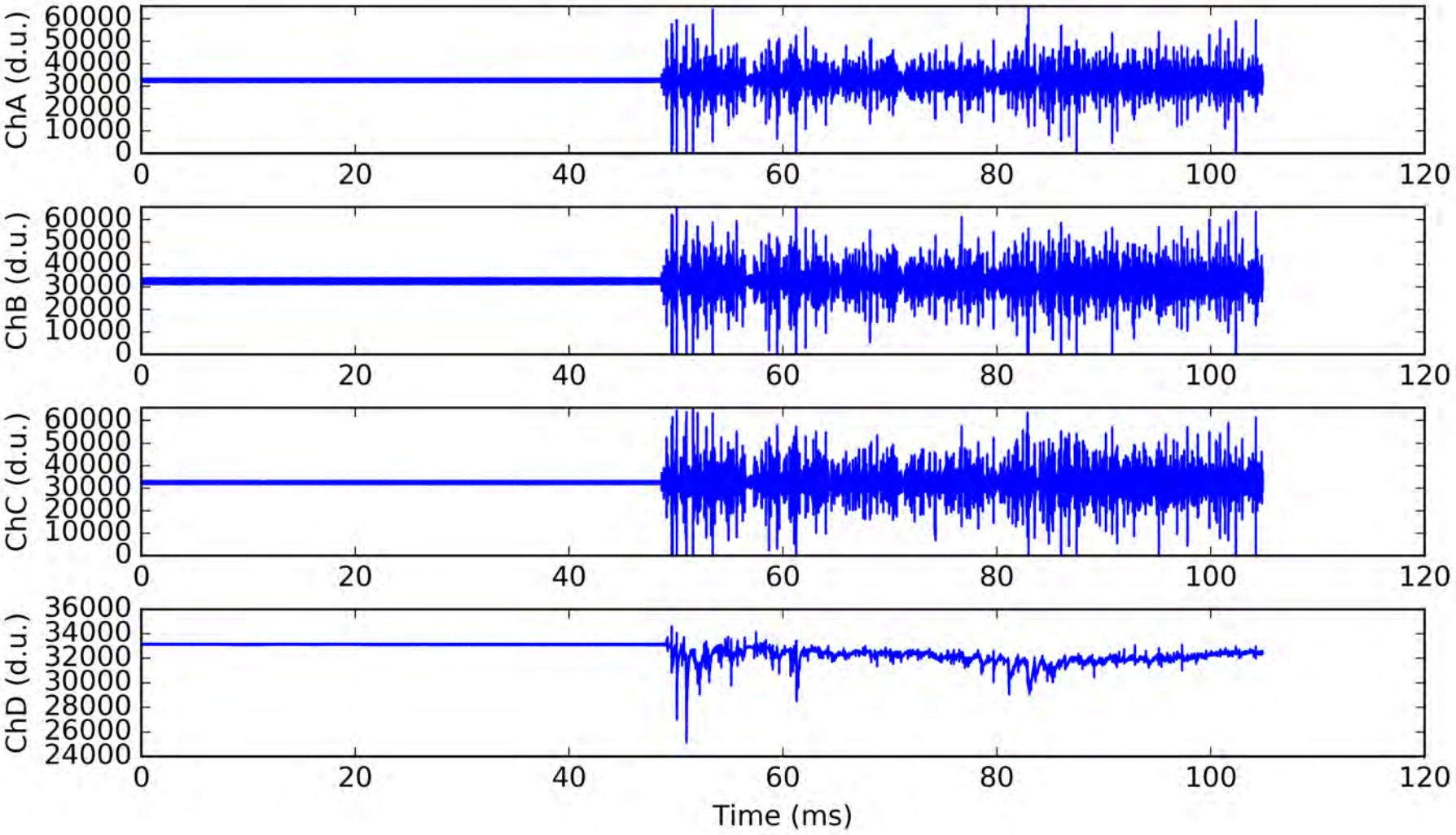
One sensor used for modelling electric current.

# Radio array




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

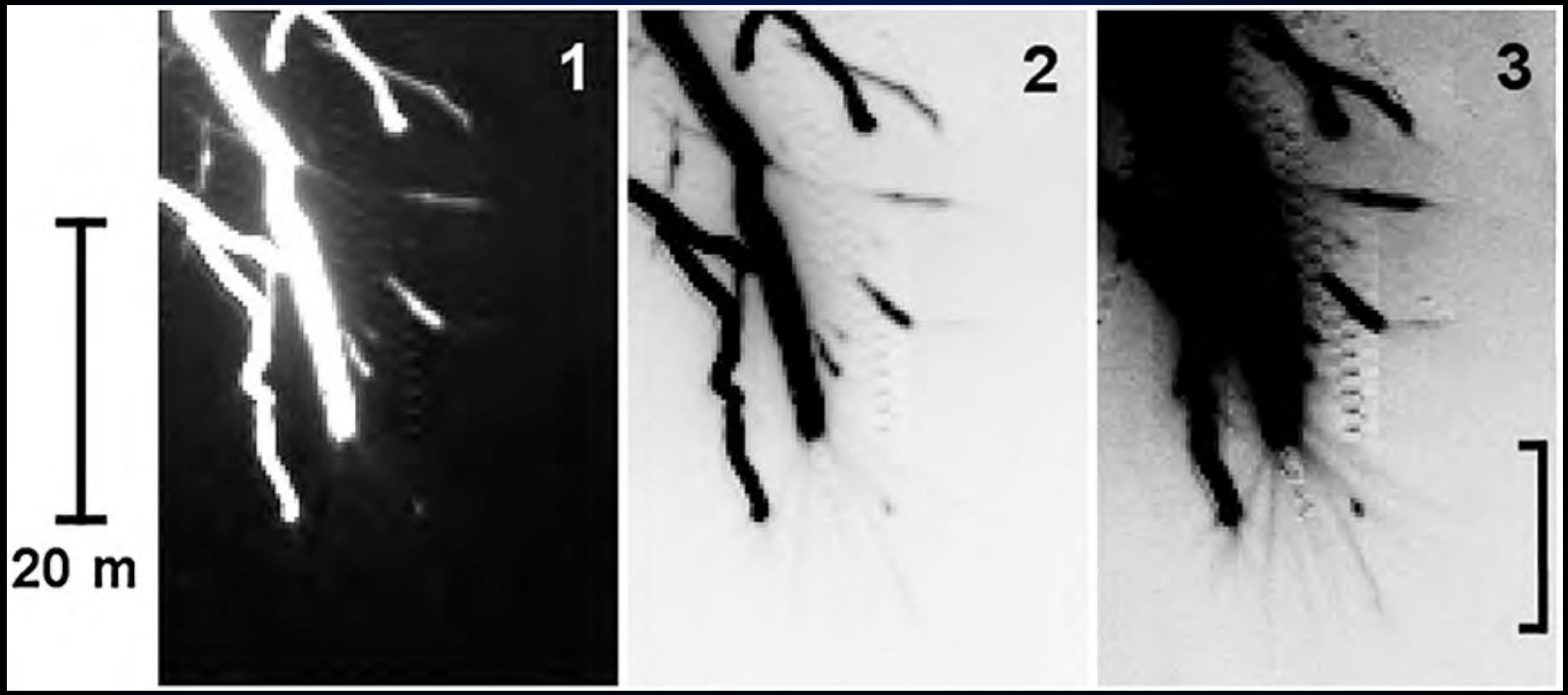
# Radio array



# Source characteristics – leaders

# 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*

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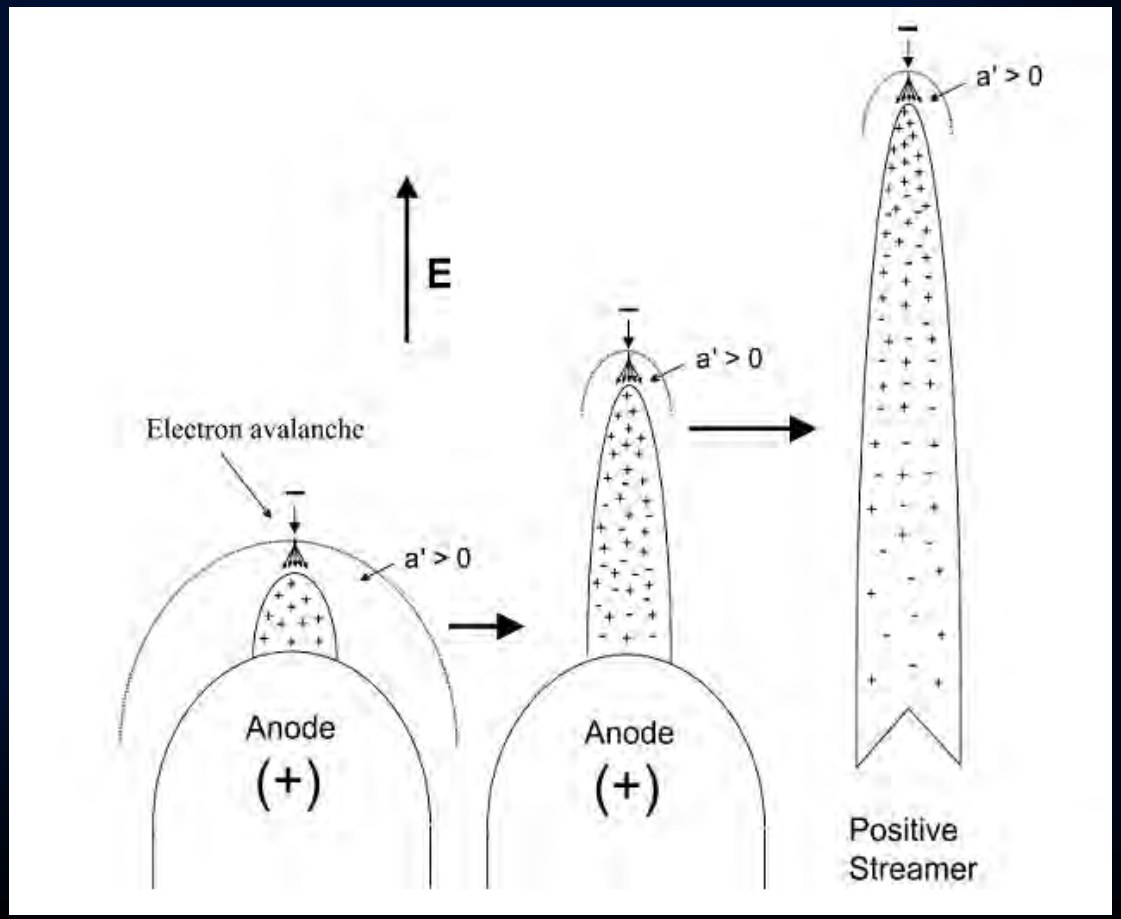


Petersen et al., 2008, *JGR*

# Source characteristics – streamers

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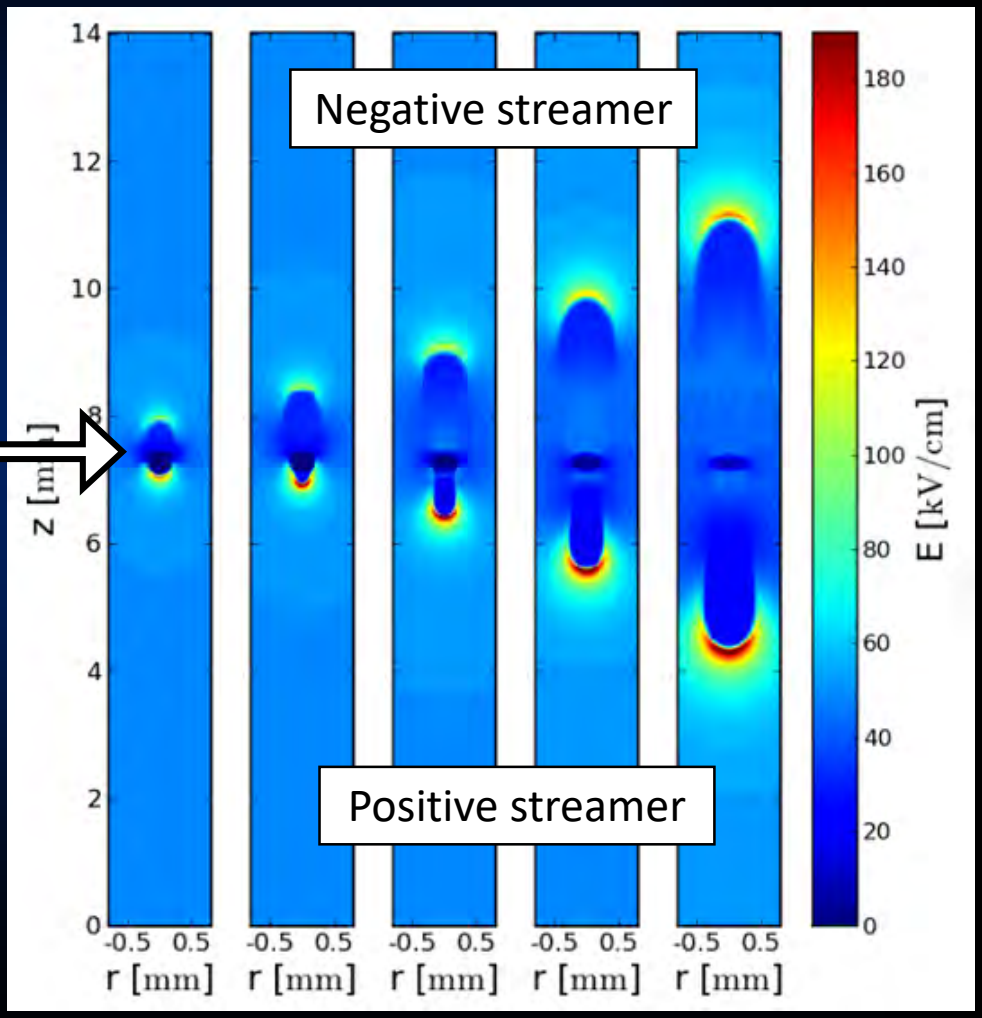
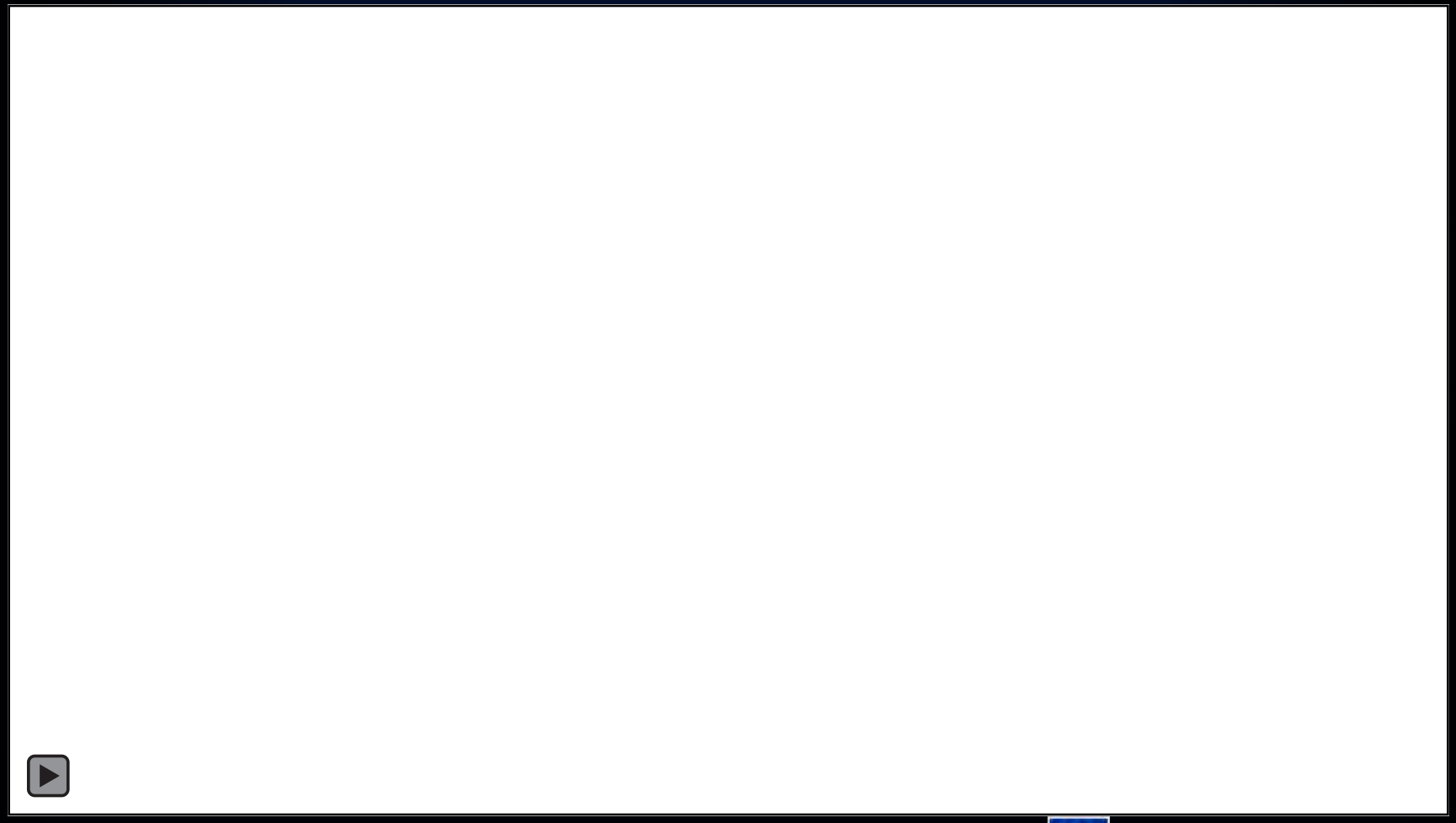
Ionization patch



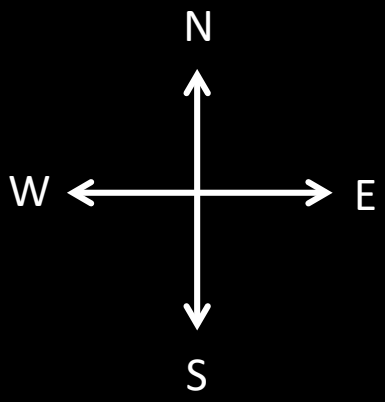

Luque et al., 2008, *J. Phys. D: Appl. Phys.*

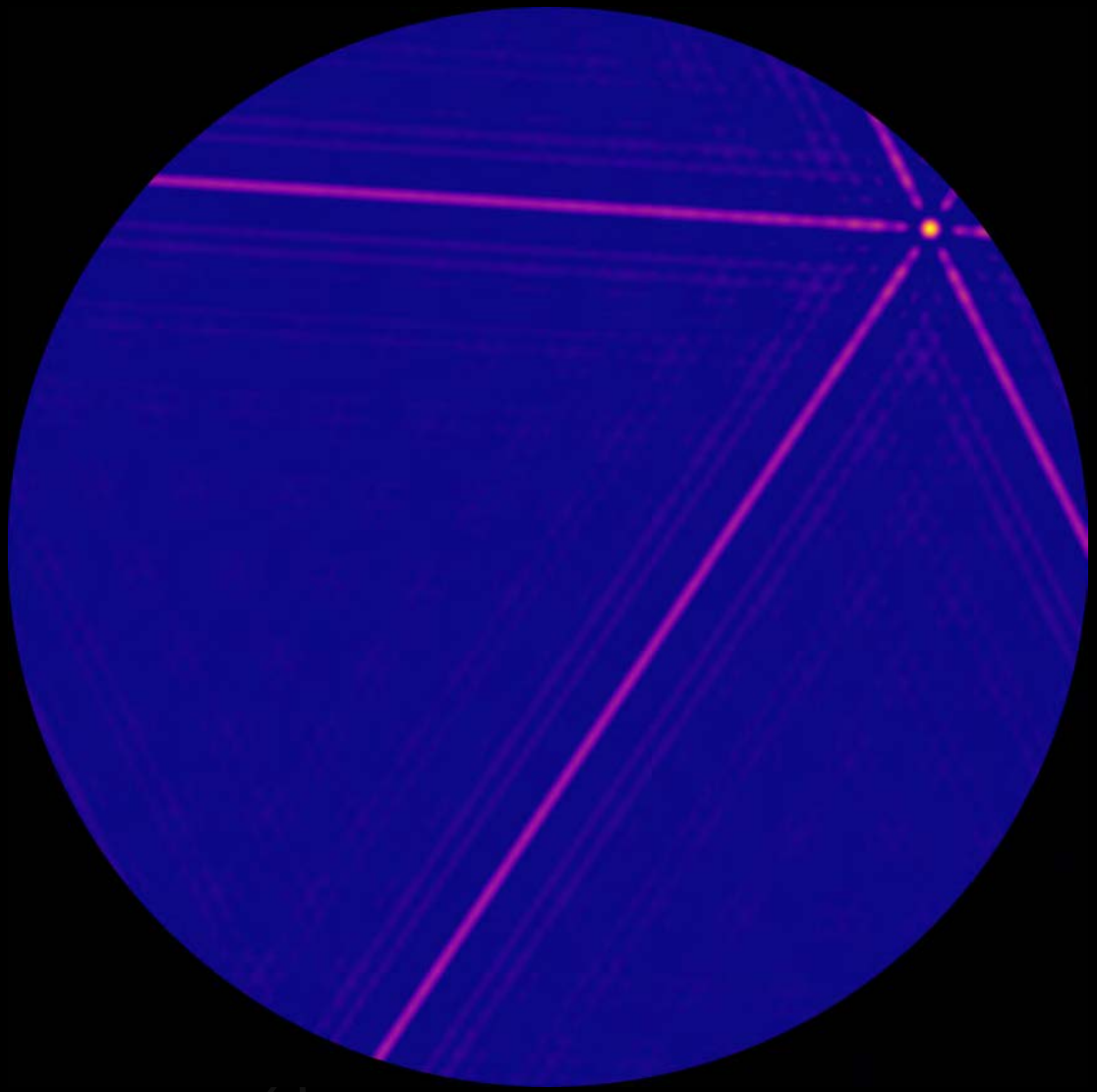
# Source characteristics – TGFs

- → 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



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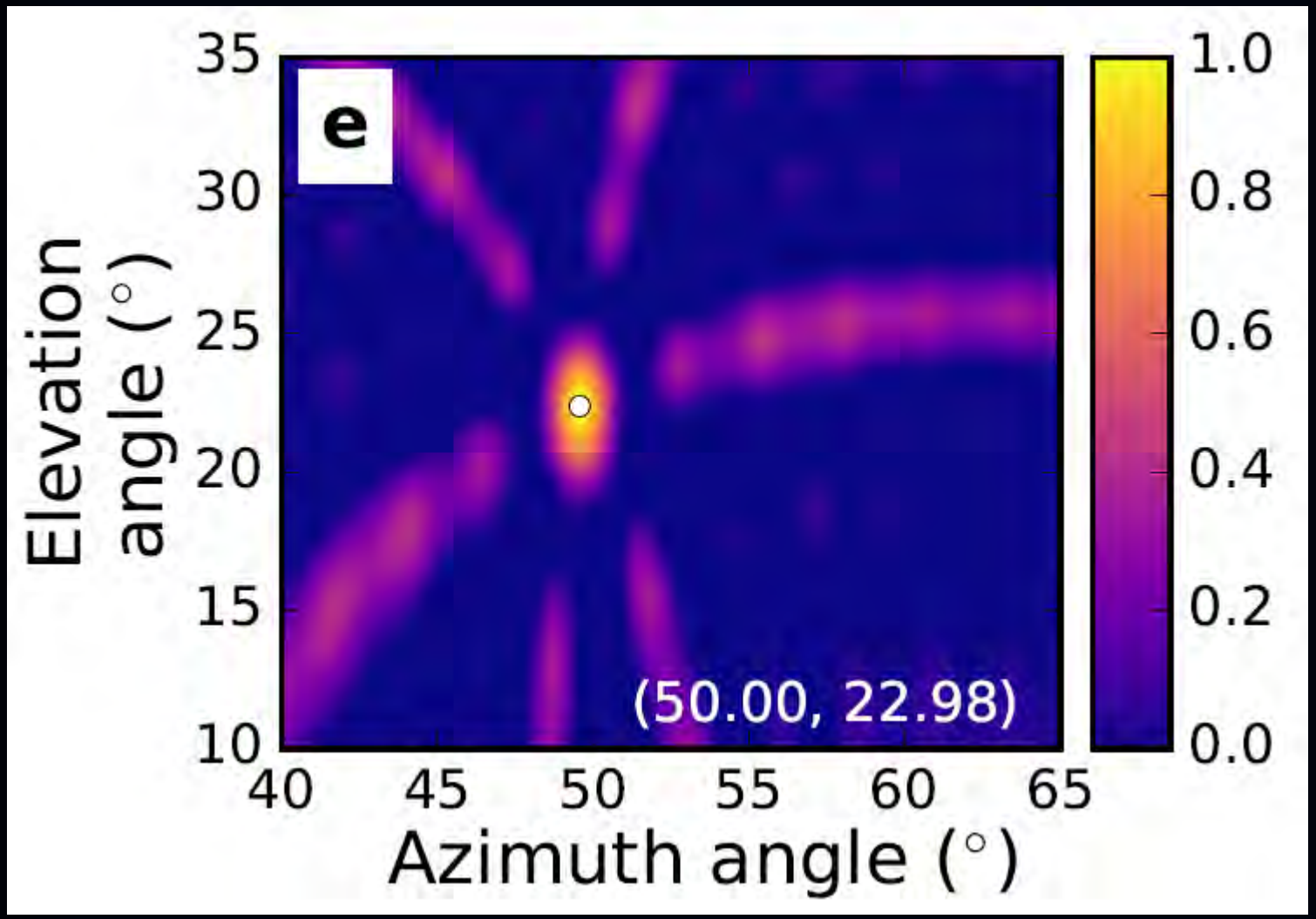

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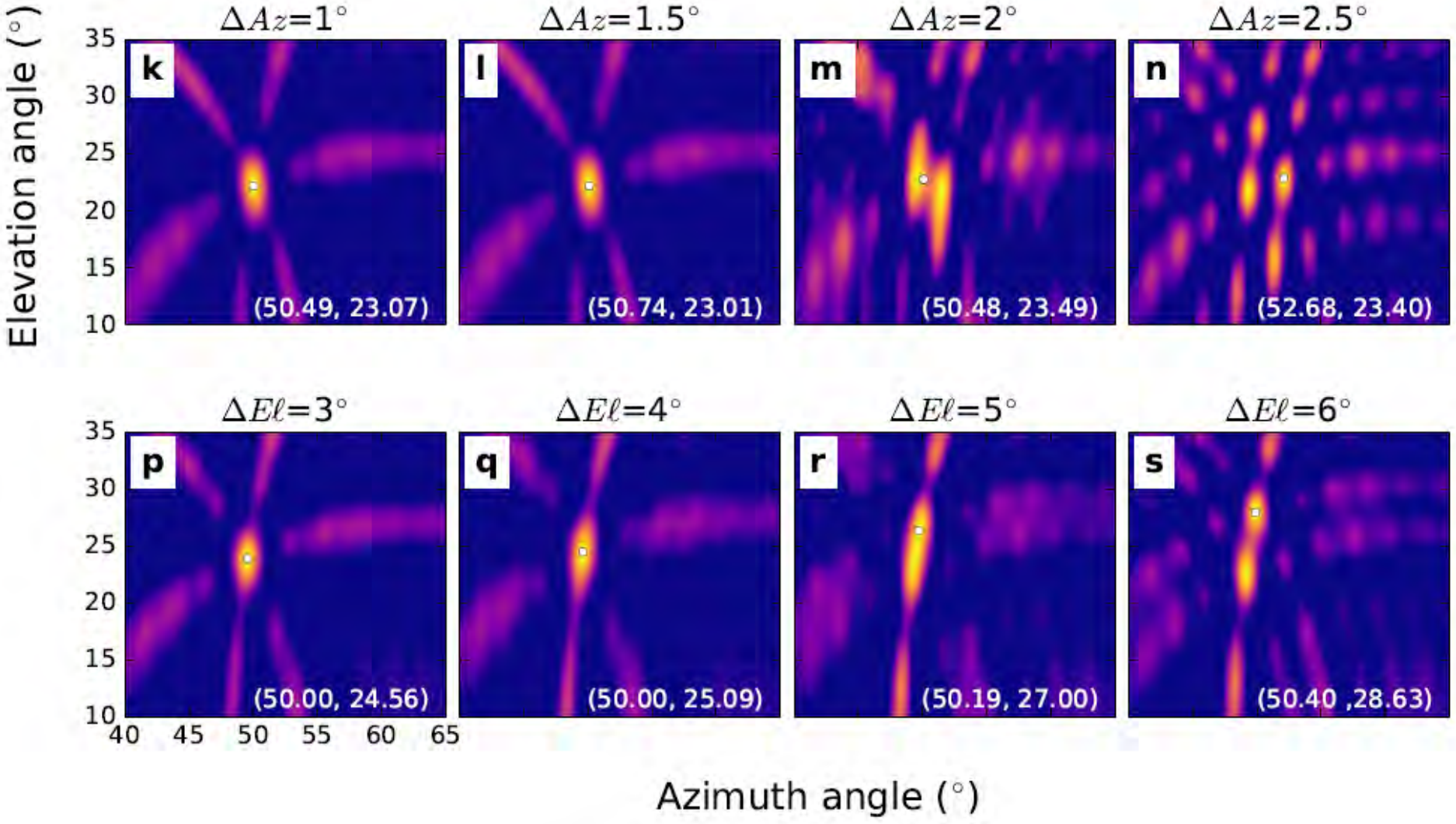

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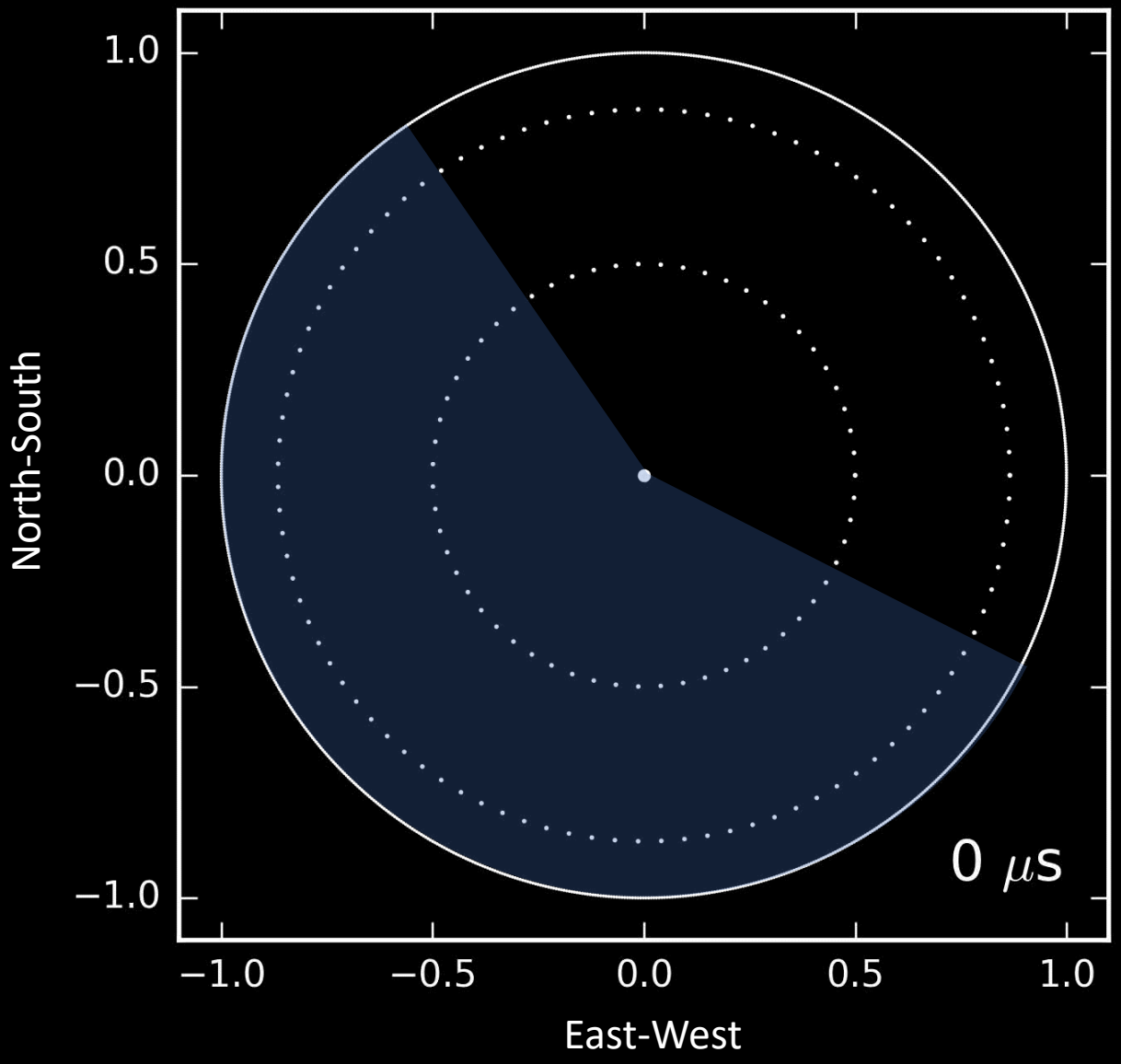

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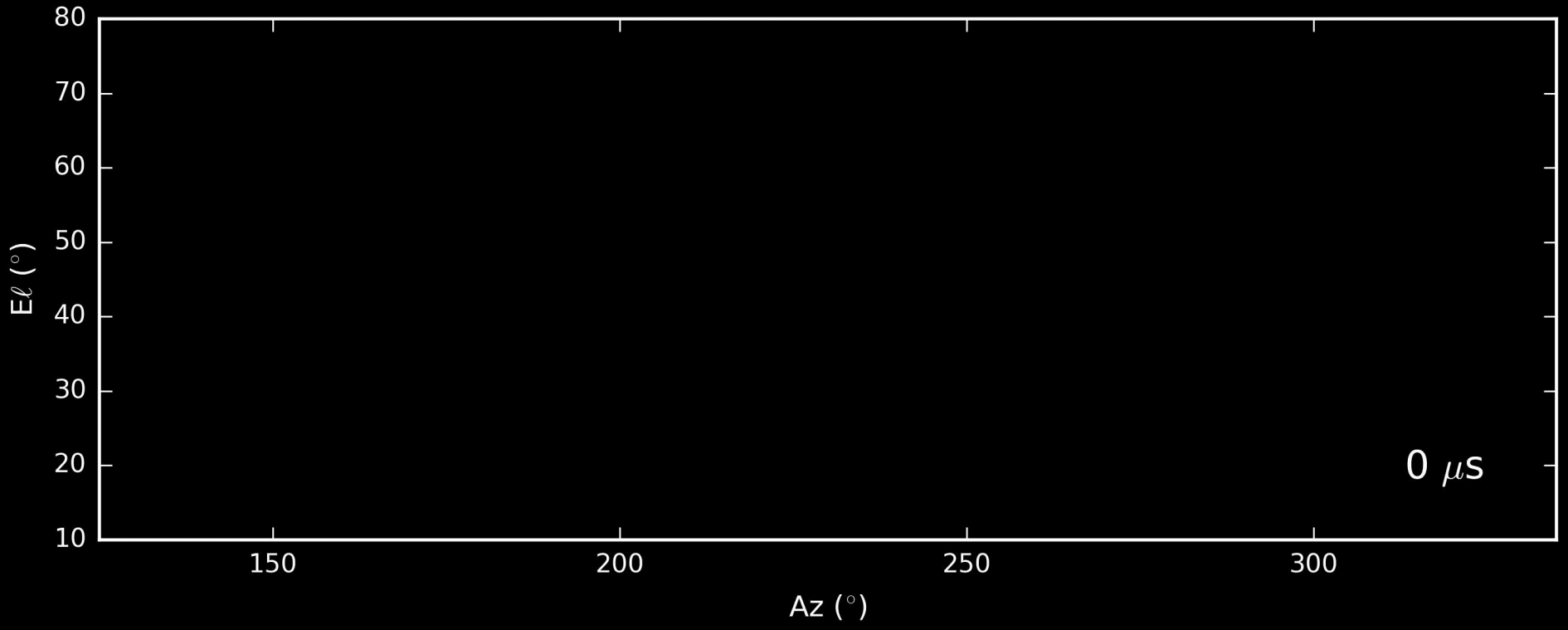

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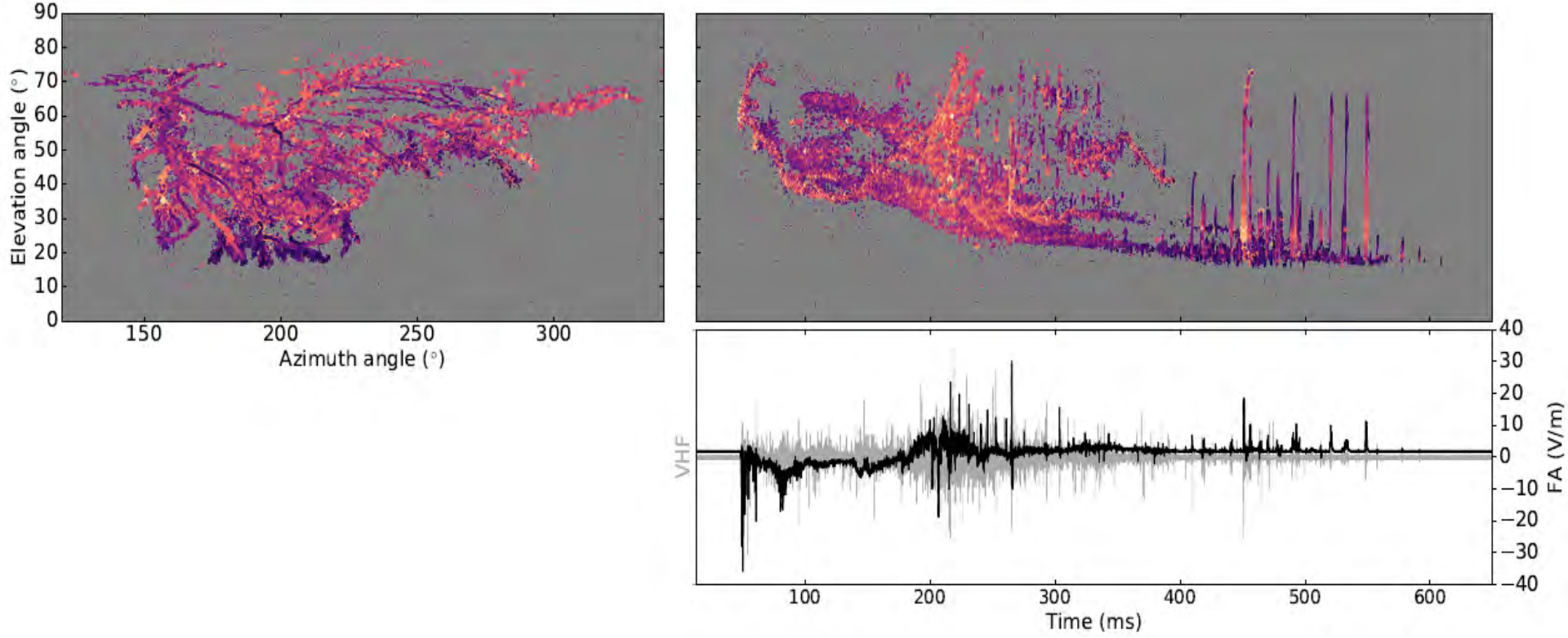
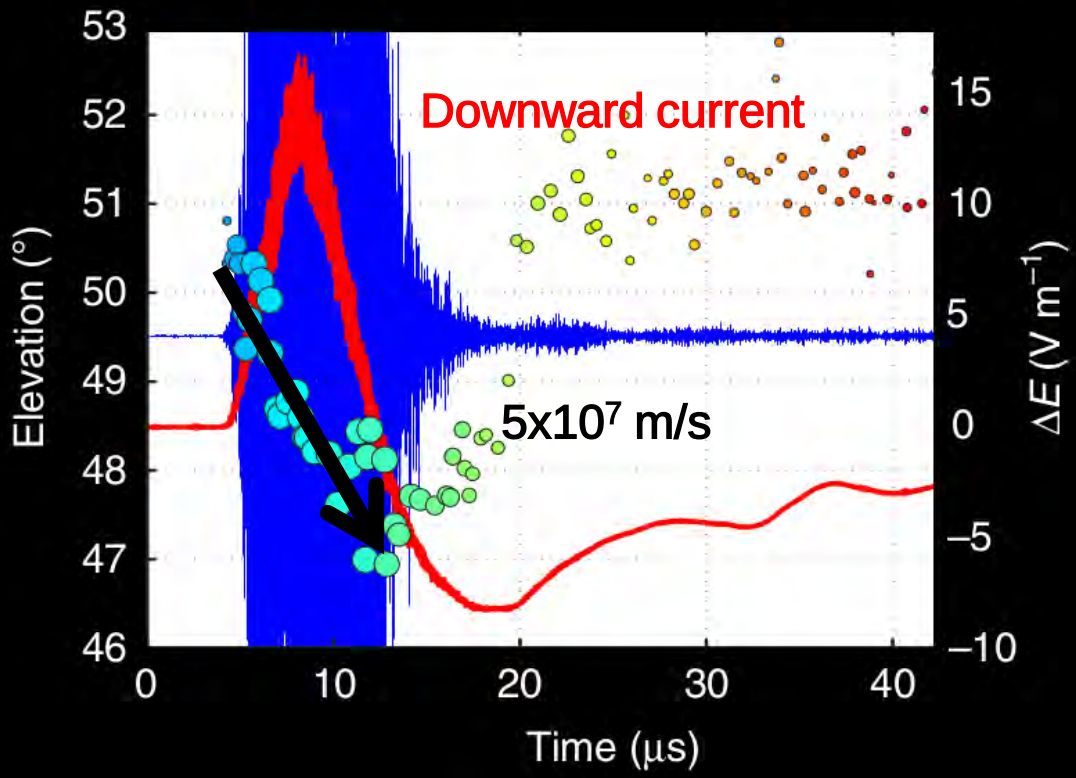
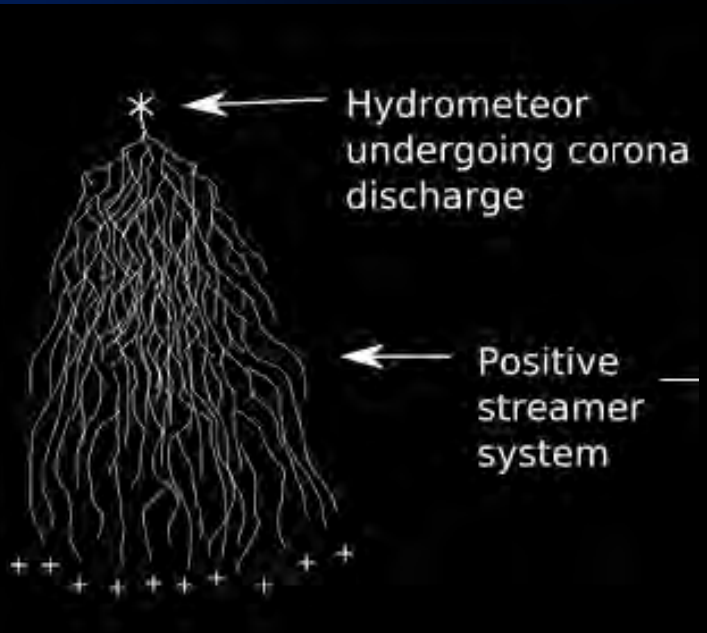


# Results – lightning initiation

- → 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.



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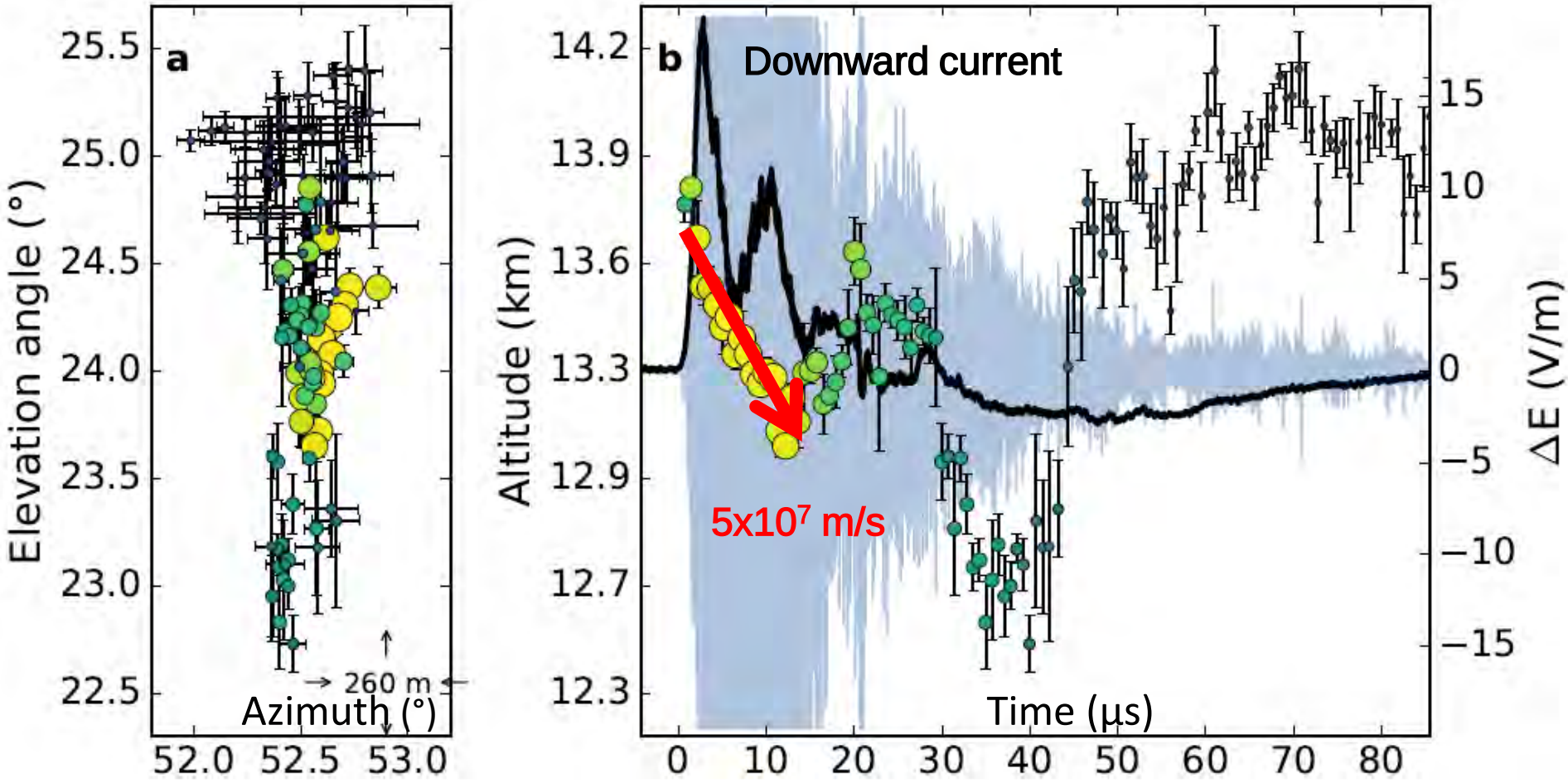
# Results – lightning initiation

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



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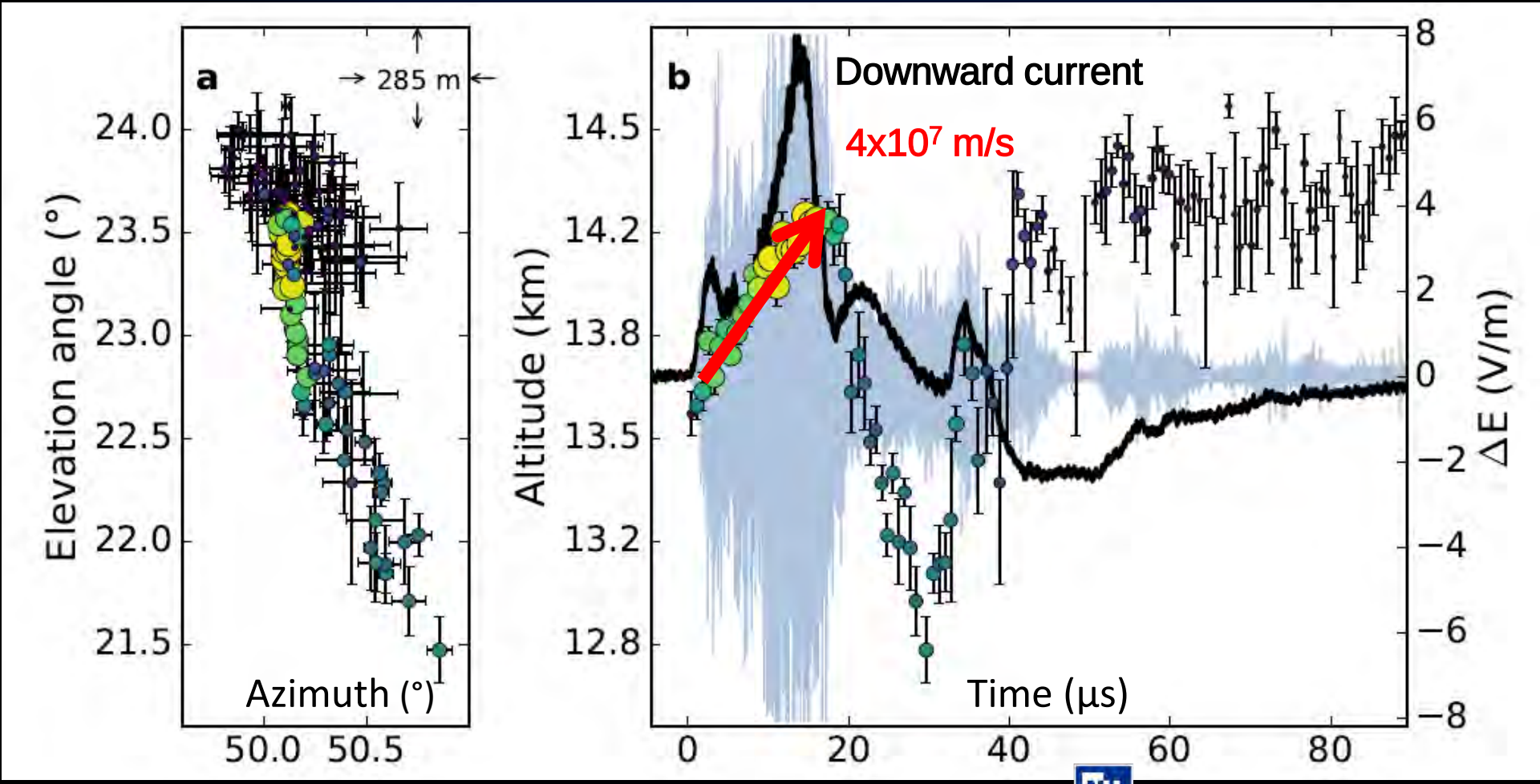
# Results – lightning initiation

- → NBE study with interferometer (Tilles et al., 2019, *Nat. Comms.*).
- → NBEs generated by fast ($10^7$ - $10^8$ m/s) negative breakdown, tens of kA.
- → Negative streamers may initiate some lightning.
- → In disagreement with lightning initiation theories involving positive streamers.



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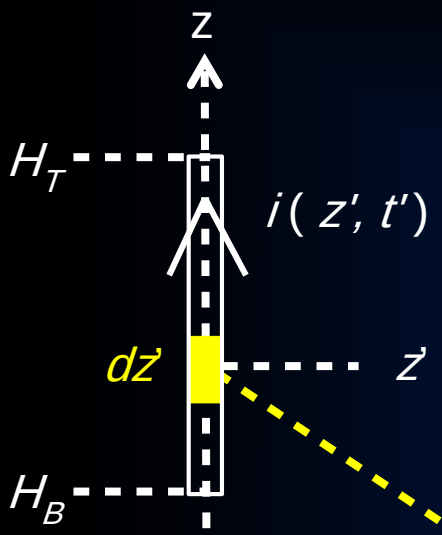
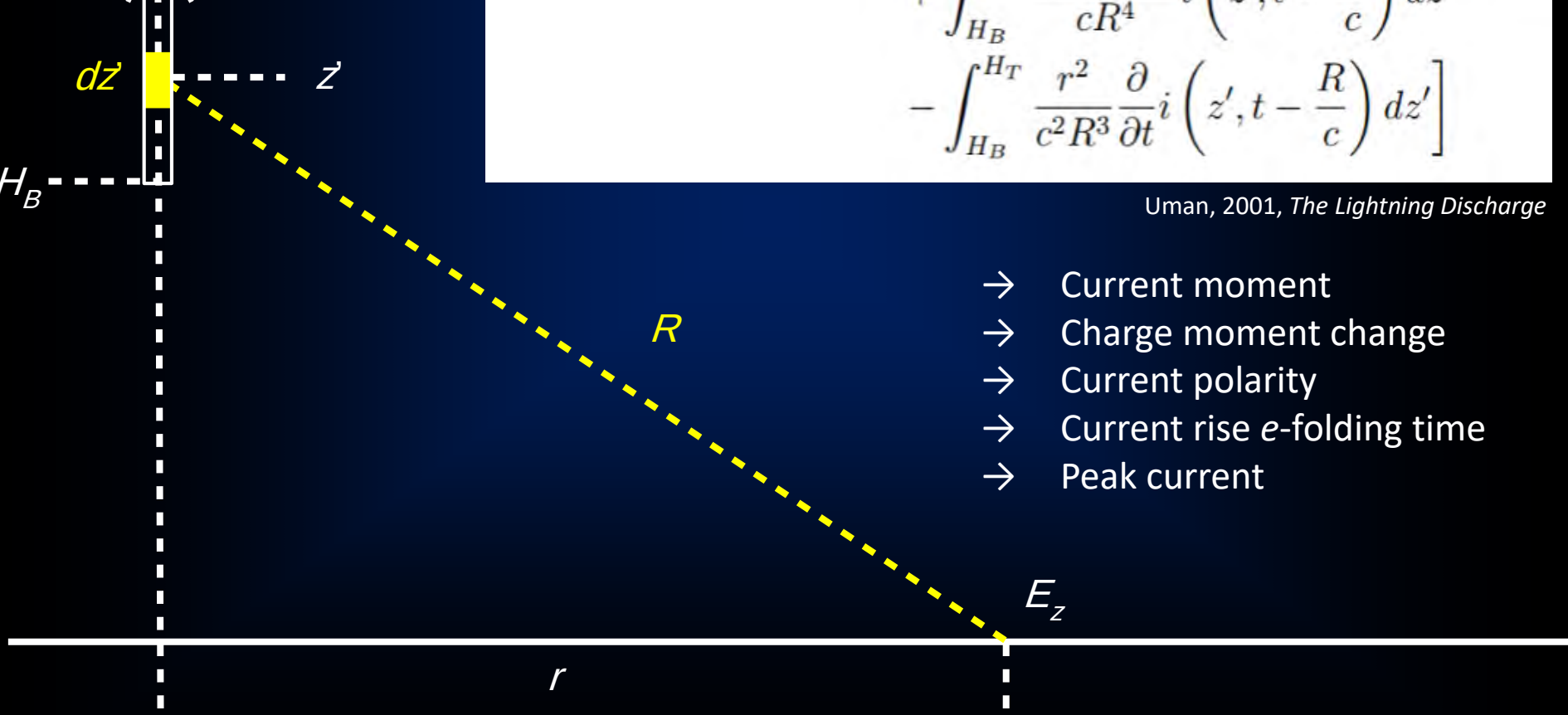
# Extras

# Fast antenna and electric current




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

Uman, 2001, *The Lightning Discharge*




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