Interferometric Lightning detection at Auger

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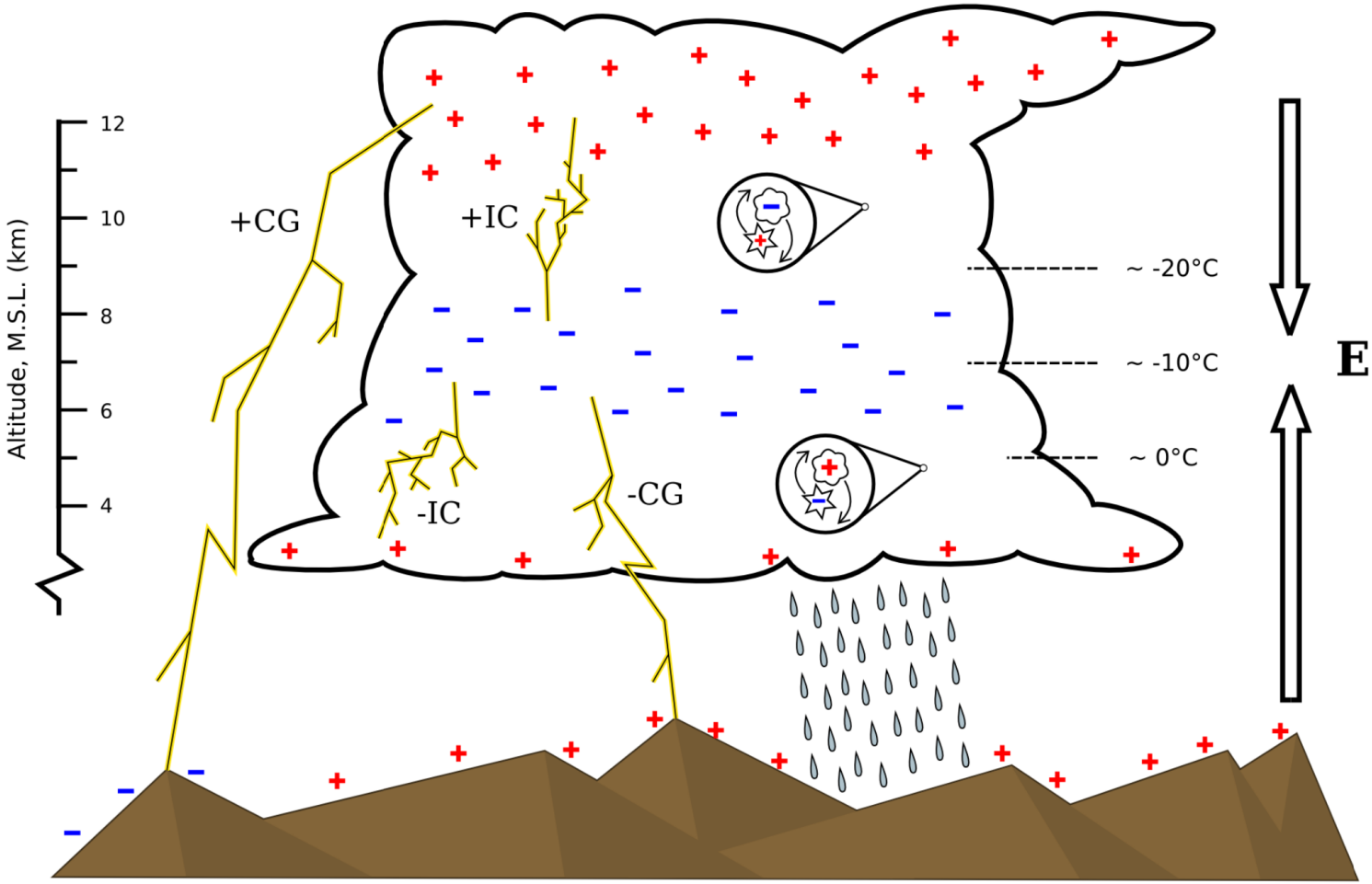
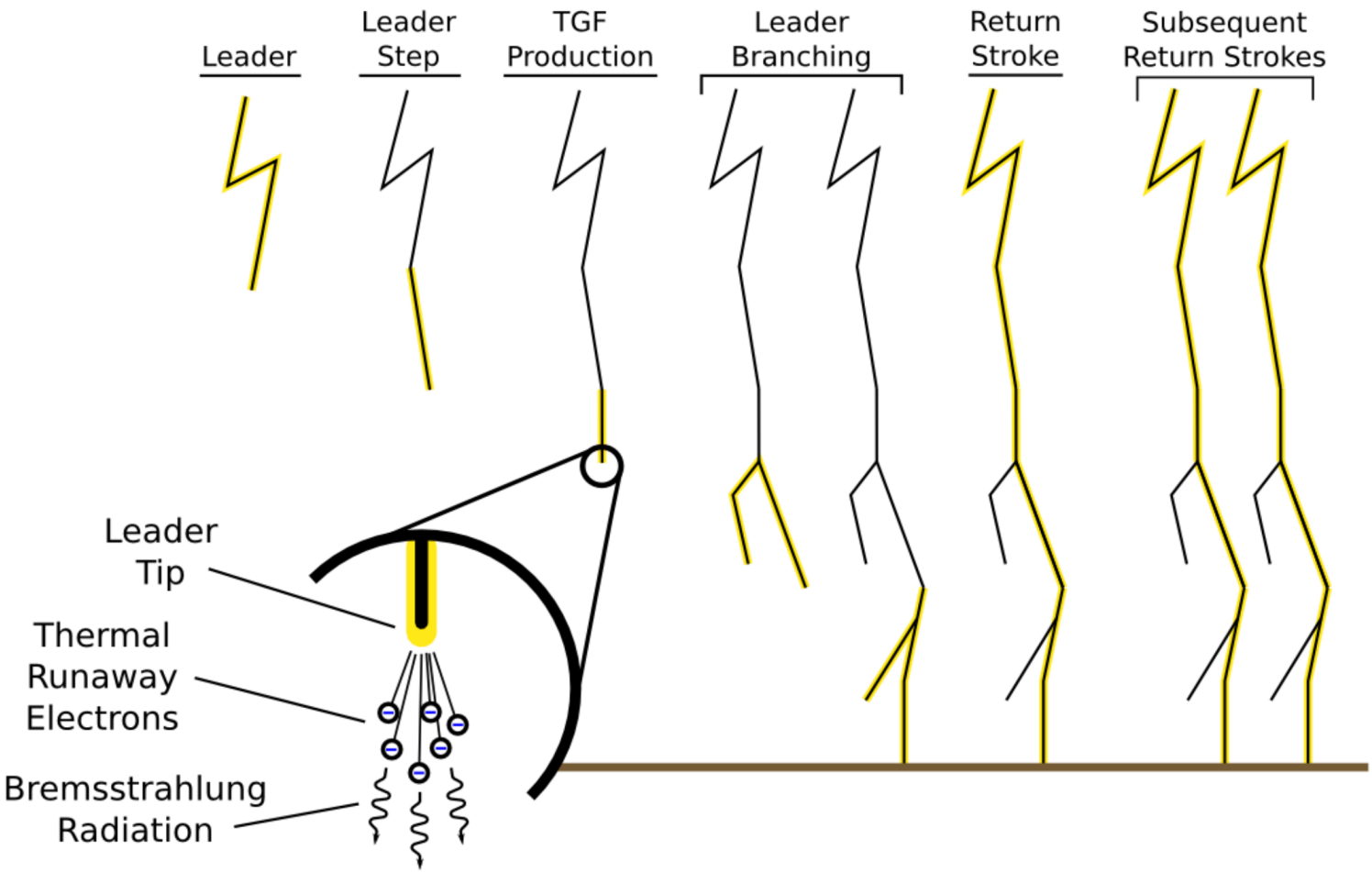
Thunderstorms and Lightning



J. Remington's PhD thesis

Thunderstorms and Lightning, very, very frightening..



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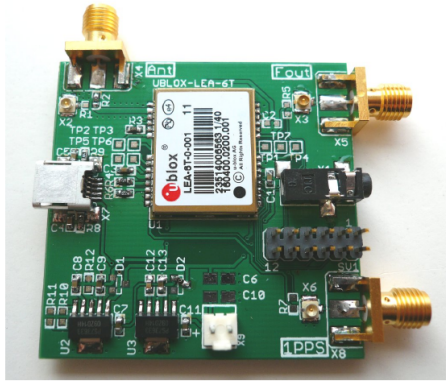
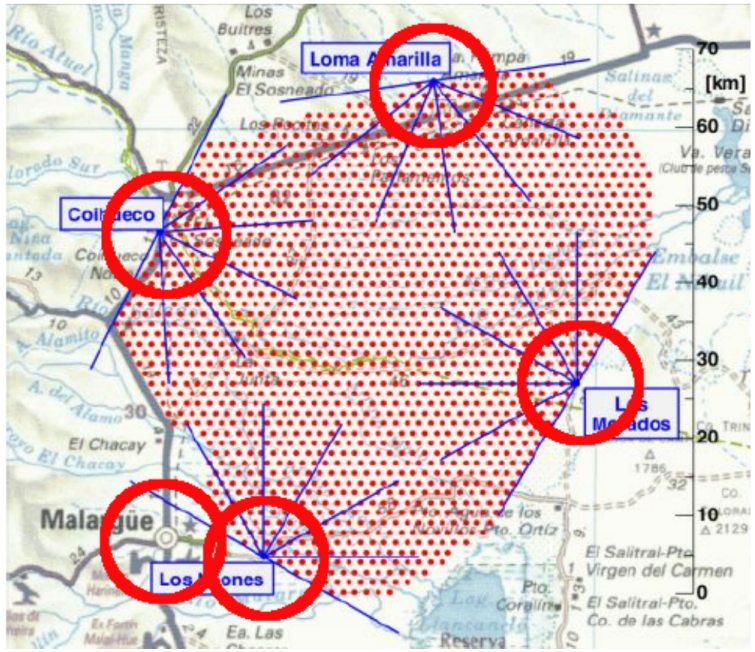
- radio pulses from Return Strokes in LF (kHz) regime, and from Streamers and Leaders in VHF (MHz) regime

Lightning Detection at Auger

- Thunderstorm conditions measured using E-field mills
- Lightning strike detected using commercial solution:
  - 5 Boltek StormTrackers
  - 10 kHz to 90 kHz
  - GPS Timing by uBlox LEA-6T
  - usable for trigger only



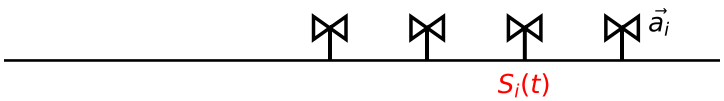


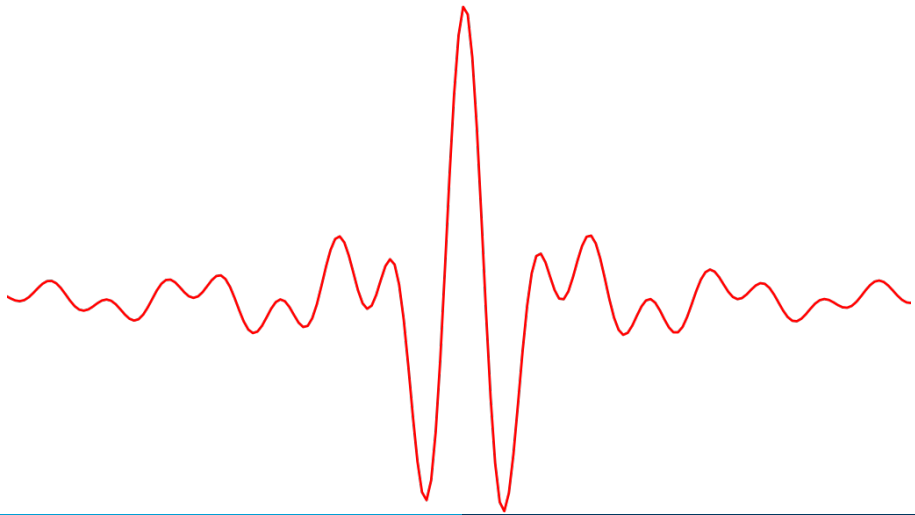
L. Niemietz's PhD thesis

Radio Interferometry

Interferometry: Amplitude + Timing information of the signal

- Measure signal $S_i(t)$ at antenna $\vec{a_i}$





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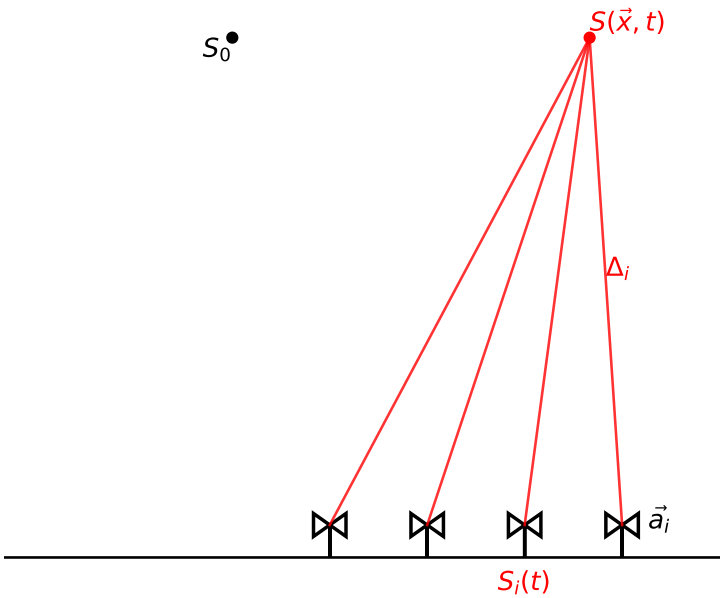
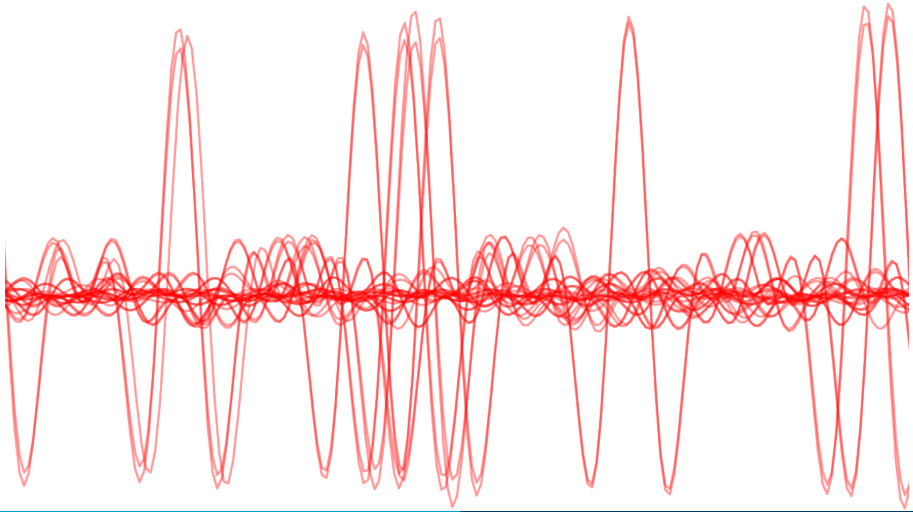


- Measure signal $S_i(t)$ at antenna $\vec{a}_i$
- Calculate light travel time

$$\Delta_i(\vec{x}) = \frac{|\vec{x} - \vec{a}_i|}{c} n_{eff}$$

- Sum/Multiply waveforms accounting for time delay

$$S(\vec{x}, t) = \sum S_i(t + \Delta_i(\vec{x}))$$



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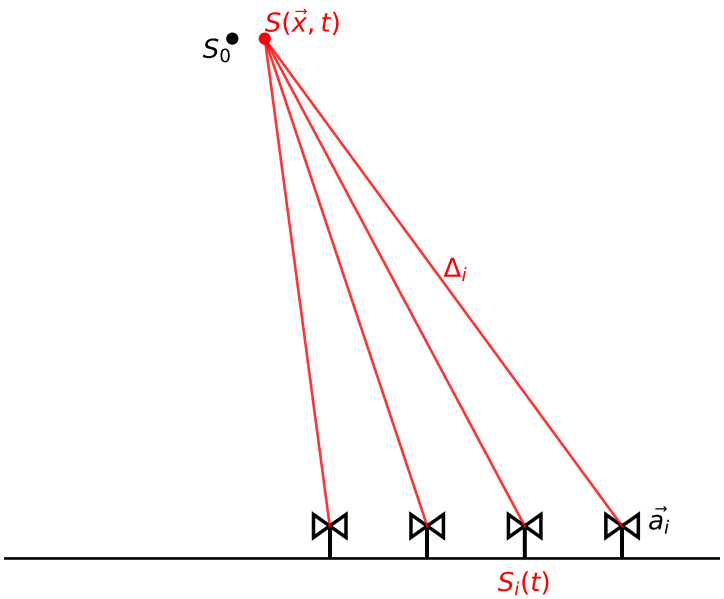

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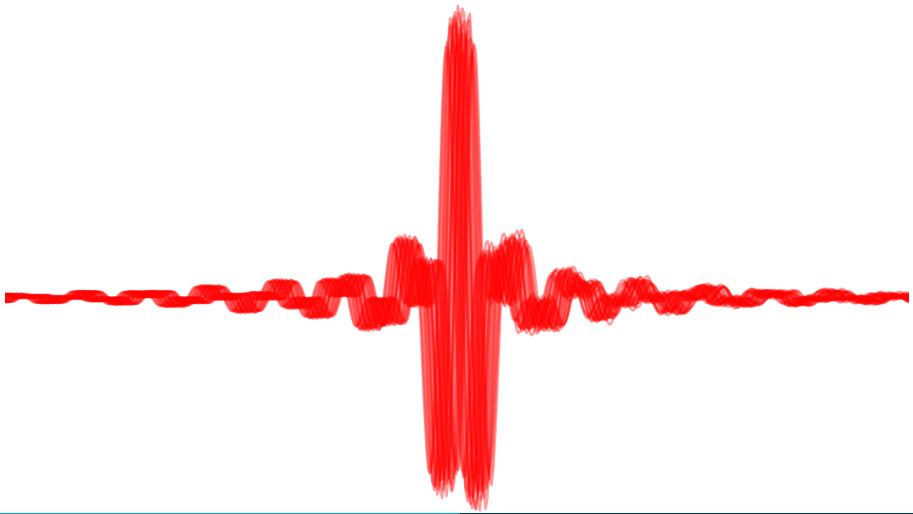

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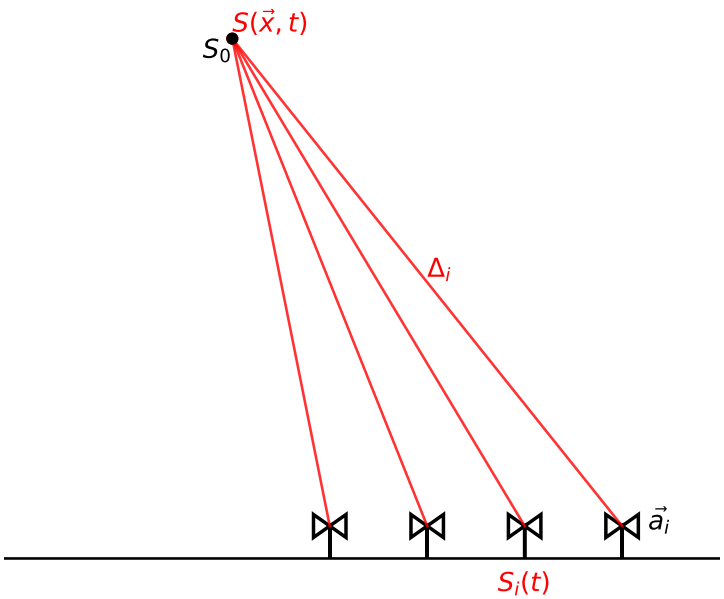

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Radio detection for Lightning vs Air Showers

Rule of Thumb for Radio Interferometry:

'Timing accuracy must be better than 1/4 (1/12) of the period.'

.. but we are doing broadband interferometry.

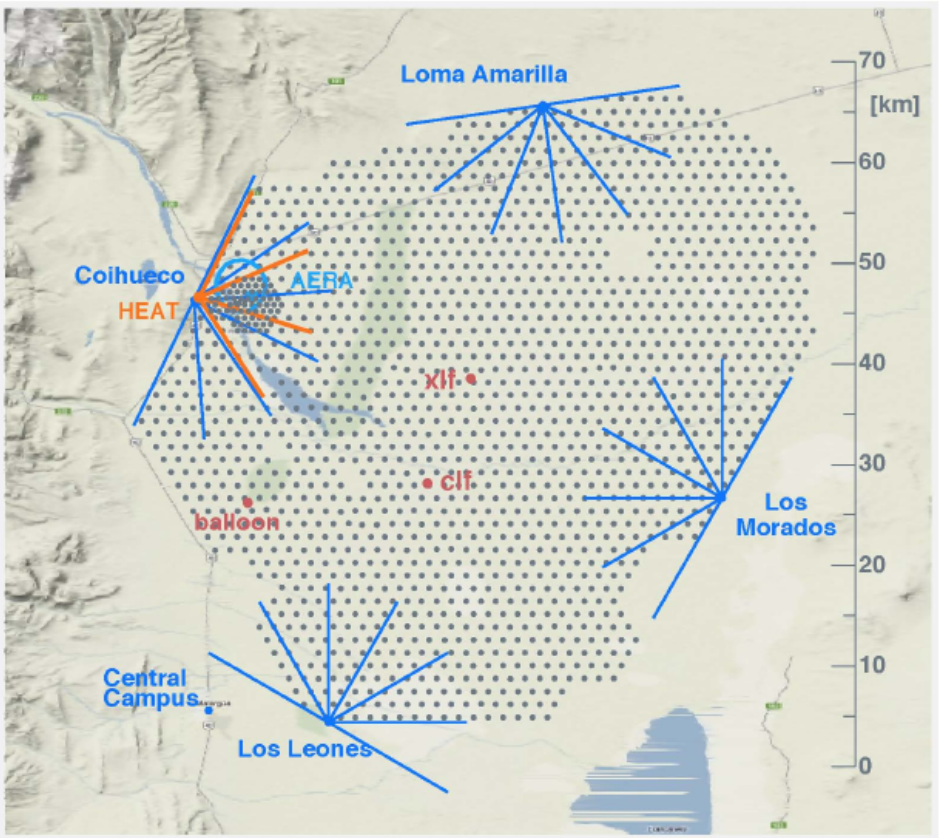
Air Showers

- relativistic emitter
- single pulse ($\lesssim 10\,\mathrm{ns}$)
- localised footprint (projected around shower axis)

Lightning

- extended emitter
- multiple pulses ($10\,\mathrm{ns}$ to $10\,\mu\mathrm{s}$, $\Delta \sim 10\,\mathrm{ms}$)
- large footprint

AERA: Auger Engineering Radio Array



Phase I: LPDA (x24)

Phase II/III: Butterfly (x130)

Sensitivity:	30 MHz to 80 MHz
Sampling Rate:	180 MHz
Tracelength:	2048x5.5 ns $\sim$ 11 µs

L. Niemietz's PhD thesis

Lightning Interferometry: reusing AERA

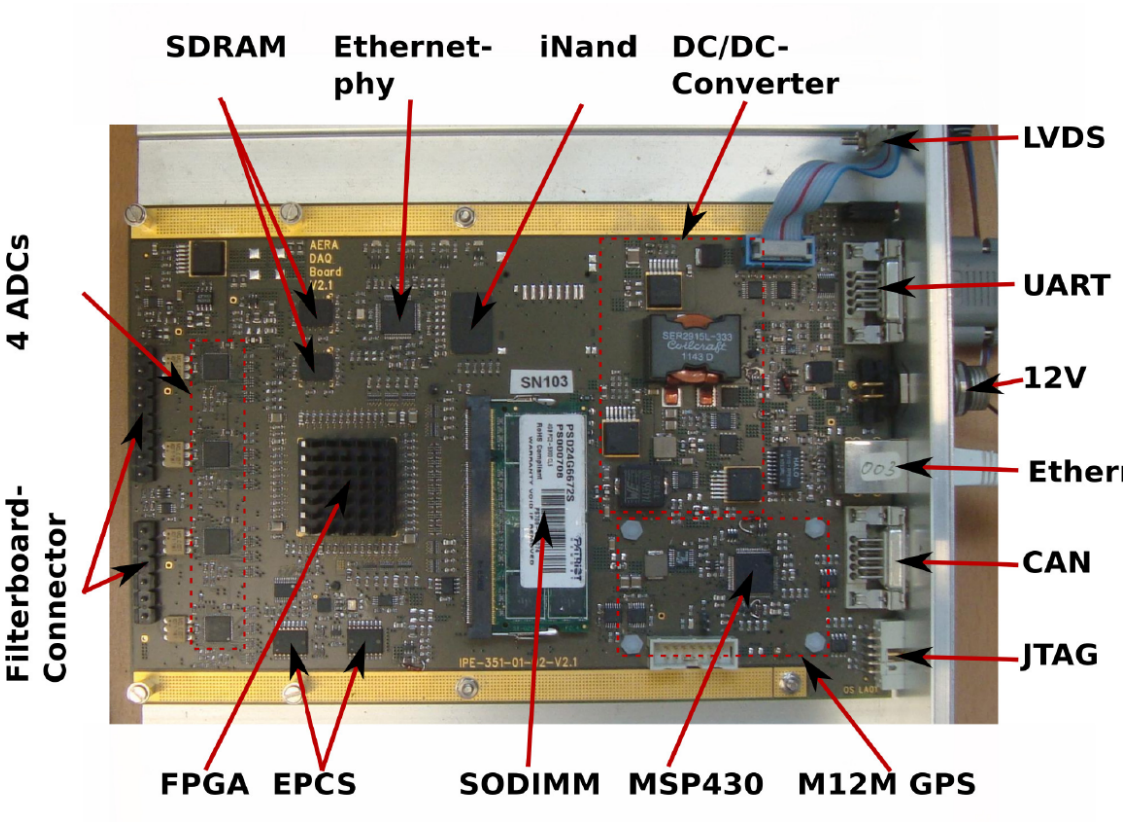
Differences between air shower and lightning signals require:

- modifications for AERA stations:
  - extending trace lengths from 11 µs to the order of 1 s,
  - and getting this data out of the field.
- trigger development
- modifications of baselines

Planned configuration:

- 4 Core stations, baselines 58 m to 127 m
  (for pulse identification/separation)
- 3 Medium range, baselines 1 km to 2.5 km
- 4 Remote stations, baselines 3.5 km to 66 km

AERA digitizer



B. Zimmerman's PhD thesis

- custom FPGA gateware for continuous sampling
- uClinux for high-level coordination

- last development 2017
- FPGA Cyclone III, and thus NIOS II CPU, unsupported...

Summary and Outlook

- Air showers and lightning emit radio signals
- AERA is not optimised for lightning interferometry, requiring modifications to the stations on multiple levels
- Second life for AERA stations in a lightning facility at Auger

Outlook for Nov. 2024:

first modified AERA station to feature extended trace lengths