Advantages of phased vs unphased arrays

Some basics: unphased arrays

- FoV of 1 antenna → $\Omega = \frac{\lambda^2}{A_{\mathrm{eff}}}$
- $P_{\mathrm{ant}} \propto |E_{\mathrm{sh}}|^2$ and $V_{\mathrm{ant}} \propto |E_{\mathrm{sh}}|$
- $\mathrm{SNR} = \frac{P_{\mathrm{sh}}}{P_{\mathrm{noise}}}$ with $P_{\mathrm{noise}} = P_{\mathrm{gal}} + P_{\mathrm{th}} + \ldots$

Unphased array:

- each antenna is a single detection unit
- all antenna signals can be incoherently summed

→ $$P_{\mathrm{array}} \propto \sqrt{N_{\mathrm{ant}}} P_{\mathrm{ant}}$$

Some basics: phased arrays

If source is spatially resolved → coherent summation of signals
→ sum the delayed signals from each antenna

- $P_{\rm array} \propto N_{\rm ant} P_{\rm ant}$ and $V_{\rm array} \propto \sqrt{N_{\rm ant}} V_{\rm ant}$
- $\mathrm{SNR}_{\rm array} = N_{\rm ant} \frac{P_{\rm sh}}{P_{\rm noise}} = N_{\rm ant}\, \mathrm{SNR}_{\rm ant}$ → increased SNR

- FoV → $\Omega = \frac{\lambda^2}{A_{\rm eff}}$ but $A_{\rm eff\ array} = N_{\rm ant}\, A_{\rm eff\ ant}$

  → $\Omega_{\rm array} = \frac{\lambda^2}{N_{\rm ant}\, A_{\rm eff\ ant}}$

- Array spacing determined by:
  - Digitization rate
  - Maximum wavelength
  - Desired angular resolution

→ Form multiple beams to recover full FOV desired (limited only by FPGA resources)

Science cases

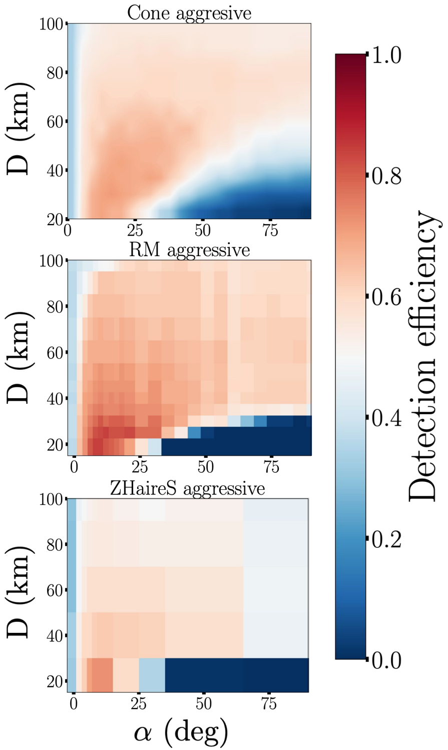
- UHE neutrinos:
  - cosmogenic → sensitivity
  - point sources / MM → +angular resolution +sky coverage
- UHECR → +FoV for down-going events
- UHE gamma rays (?) → discrimination method

- radio astronomy → radio waves are frequency delayed when crossing cold plasma (source, ISM, IGM…) → correct the dispersion, frequency by frequency, to retrieve the signal

  → dynamic frequency spectra → incoherent/coherent time-frequency analysis

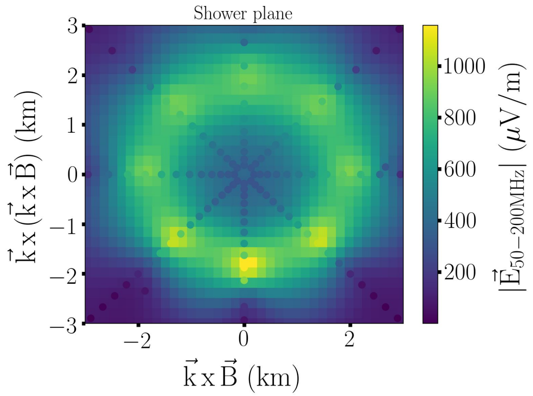
Array geometries

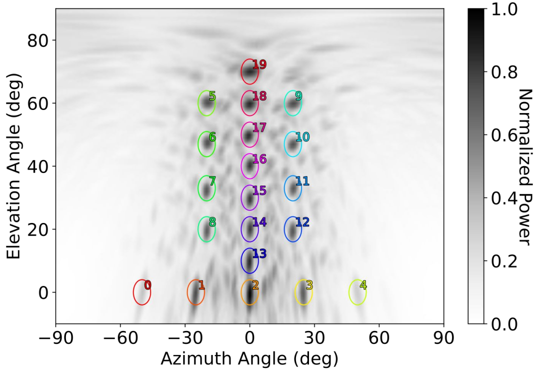
- array spacings
- clustering
- elevation
- patterns
  → secondary beams

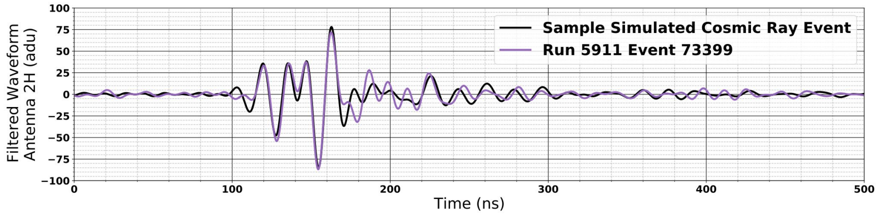


Trigger and noise mitigations

- trigger conditions:
  - radio footprint i.e. Cherenkov pattern
  - time traces (beam power sums, hilo conditions)
  - directional masking (for RFI)
- noise mitigations:
  - RFI / human made noises
  - Weather like noise
  - vetoing CRs







Technical and logistical challenges

- data throughput:
  - raw / processed data
  - cables vs wireless
- power consumption:
  - autonomous station
  - grid powered
- deployment:
  - locations
  - accessibility
  - logistics

Analysis / reconstructions

- direction:
  - “triangulation”
  - beam trigger
  - template fitting
  - ML
- energy:
  - fluence summation
  - template fitting
  - ML
- composition:
  - radio Xmax
  - template fitting

Crazy idea(s)

Phasing the whole sky with 100 arrays of 100 antennas

- each array has 10x the SNR of an unphased array of 100 antennas
- FoV ~36000°
- 1 beam has about Ω_{array} ~ 7.2° at 100MHz for ideal antennas → 5000 beams
- each antennas needs to record n = d_{array}/c 2.e9 samples (0.5 ns step)

→ a buffer of ~2 TB for 100 antennas (in a 1km^2 array)

→ a processing power of ~2 Tflops (1 Nvidia Tesla v100 for 10k€ ~ 8Tflops)

Crazy idea(s)

Clusters of phased and unphased arrays → target different energy ranges

- down to which energie(s)?
- array configuration(s)?
- how many beams? (i.e. which FoV)

Backup

$$\mathrm{SNR} = \frac{V^2_{\mathrm{rms\,signal}}}{V^2_{\mathrm{rms\,noise}}}$$

$$P_{\mathrm{th}} = k_B T \Delta\nu$$

$$< V_{\mathrm{ant}} > \propto P_{\mathrm{ant}} \propto G_{\mathrm{ant}} P_{\mathrm{input}}$$

$$G \propto \frac{4\pi}{\Omega} = \frac{4\pi A_{\mathrm{eff}}}{\lambda}$$

$$G_{\mathrm{array}} = 10 \log_{10}(N_{\mathrm{ant}}\, 10^{G_{\mathrm{ant}}/10})$$

$$S(\nu) = \frac{P(\nu)}{A_{\mathrm{eff}}}\ [\mathrm{W.m^{-2}.Hz^{-1}}]$$

$$dP_\nu(\theta,\phi) = P_\nu(\theta,\phi) d\Omega = dS_\nu(\theta,\phi) A_{\mathrm{eff}}\ [\mathrm{W.Hz^{-1}}]$$

$$\mathrm{Beam\ width} = \frac{\lambda}{N\,d}$$