Brainstorming: Optimizing antennas for the horizon

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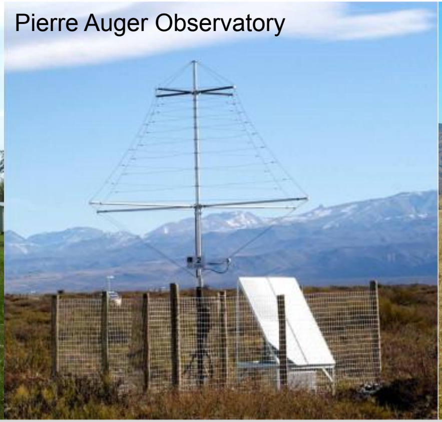
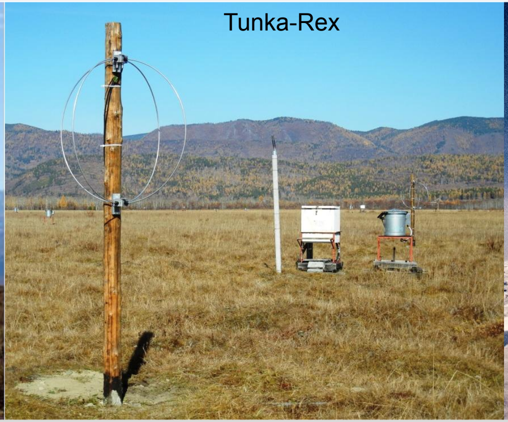
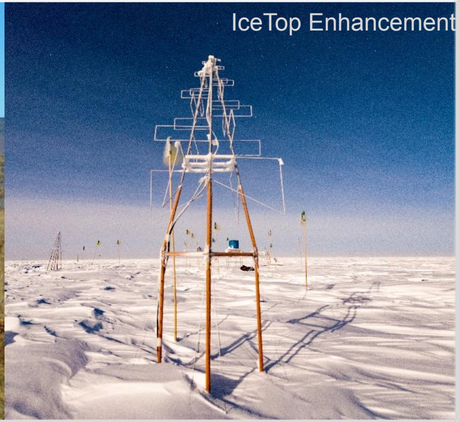


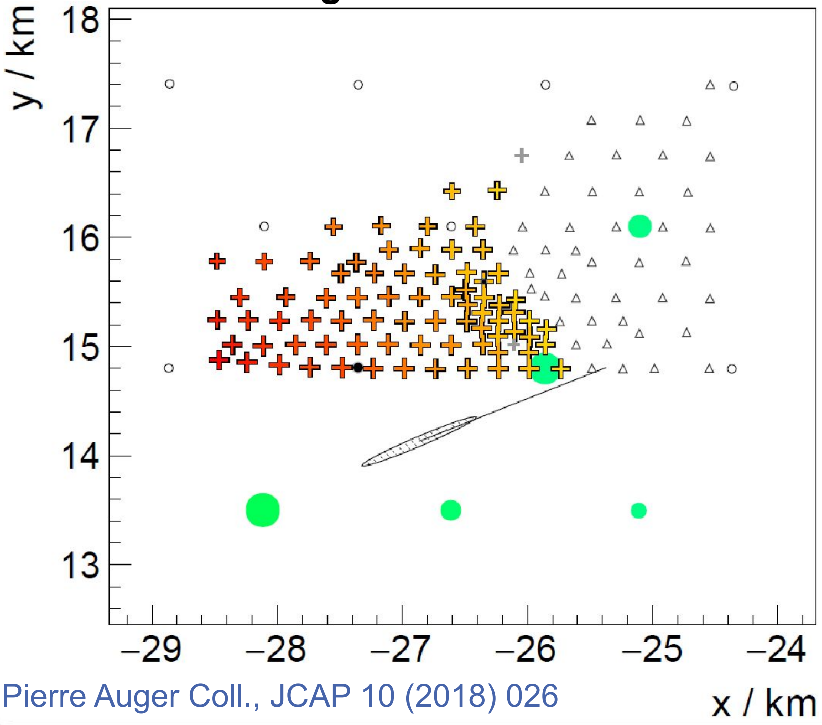




Huge footprint for inclined showers

- Enables sparse antenna arrays for highest energies at reasonable costs

Auger measurement



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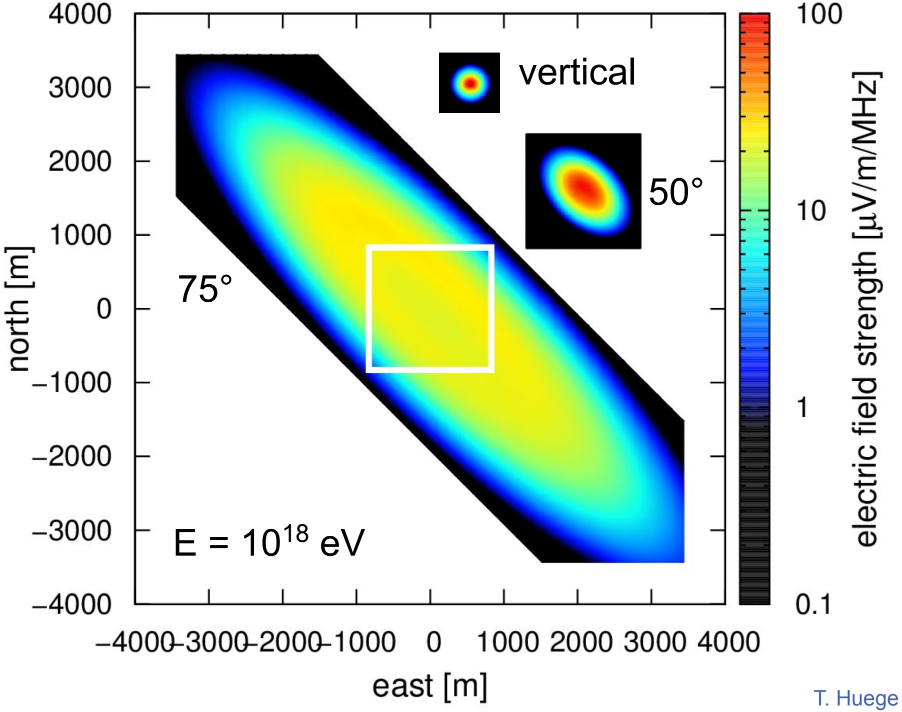
CoREAS simulations

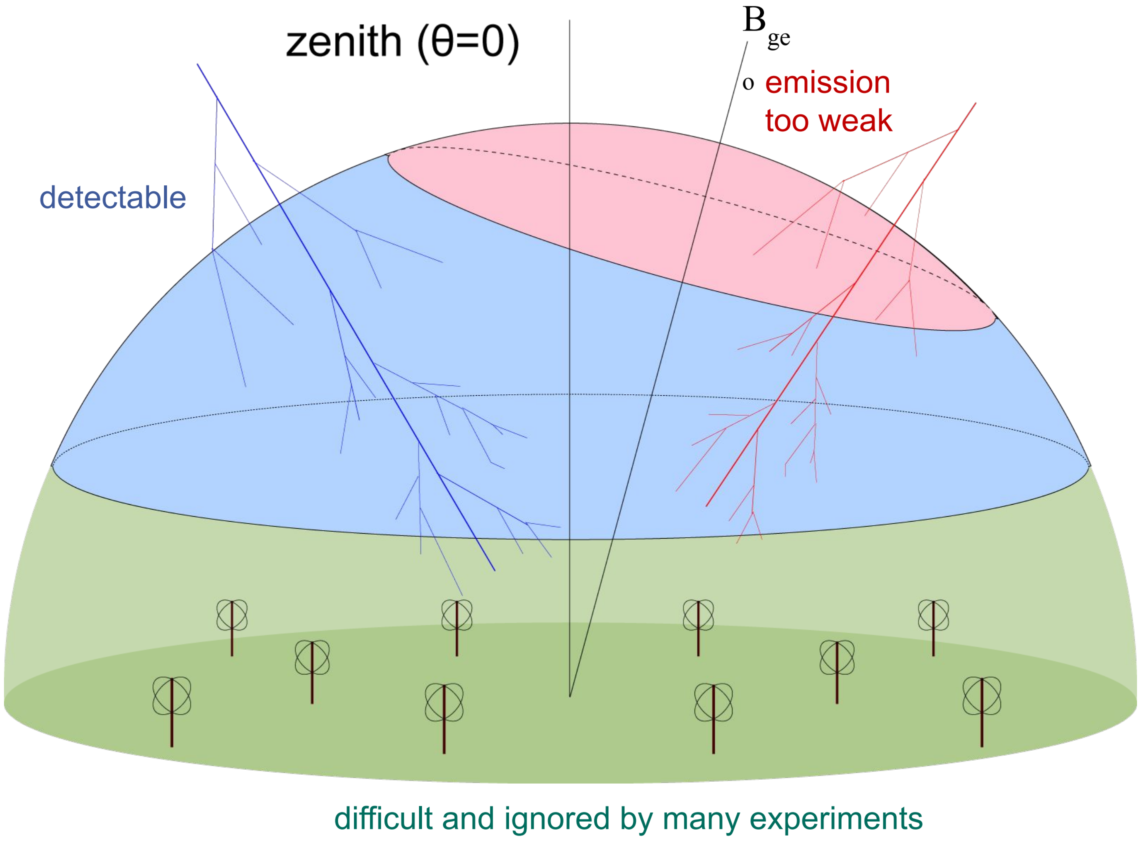


T. Huege

Traditional Radio Arrays Insensitive to Horizon

Challenges for near-horizontal radio detection

- External trigger is difficult due to low particle content
- Low signal strengths because radio signal gets diluted over large area
- RFI pulses are mostly near-horizontal
- ground absorption of signal if within 1-2° of horizon?
- Insensitive or complicated antenna gain



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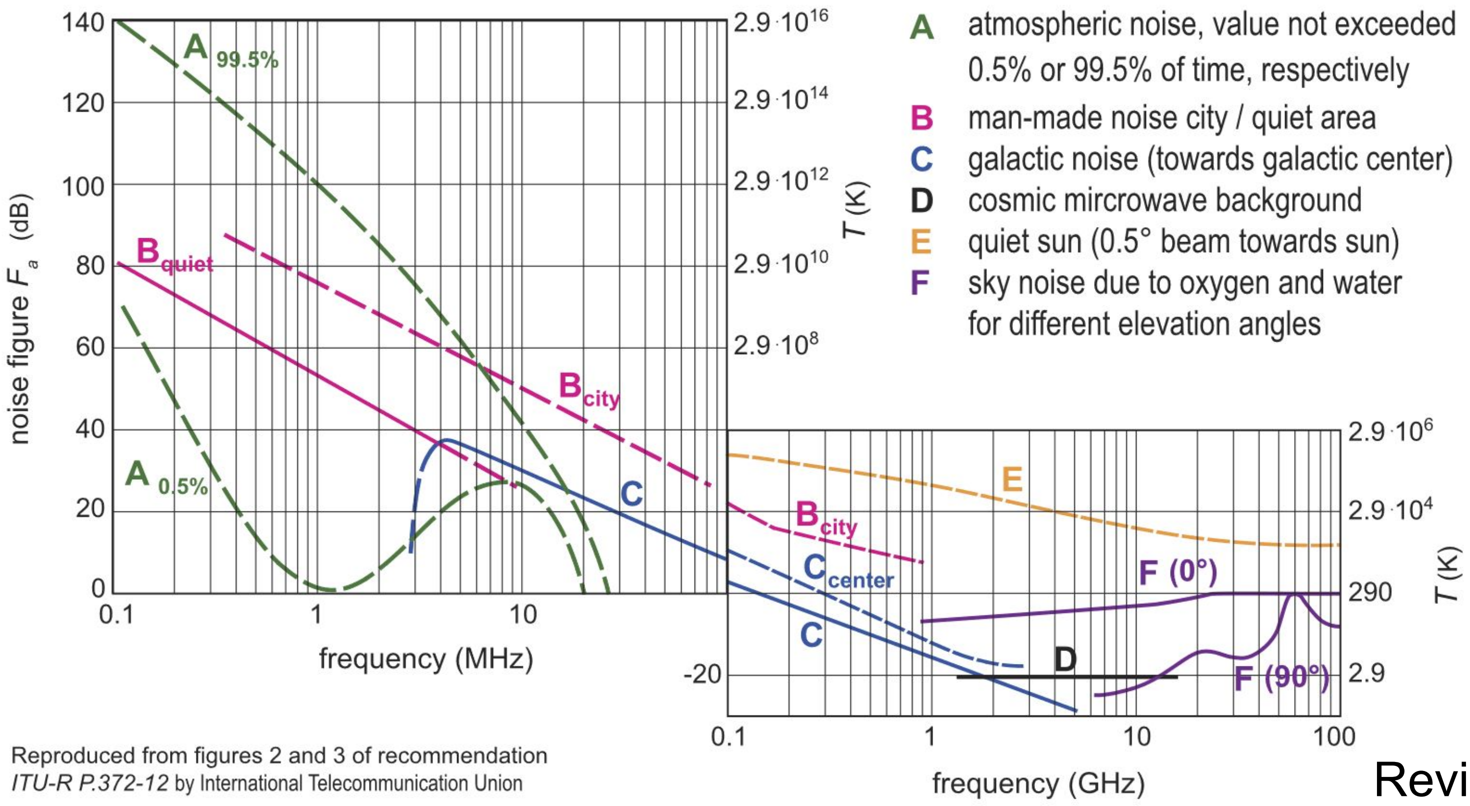
Higher frequencies have lower Galactic background (thermal may dominate)



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Review Frank

Optimizing antennas for radio neutrino detection

- Tradeoff gain versus field-of-view.
- Low frequencies (sky brighter than terrain, 200 MHz ~300 K): small field-of-view will lower threshold
- High frequencies (terrain brighter than sky): no threshold reduction
- Focus on field-of-view allowing neutrino detection (horizon +/- few degrees) – how many degrees are useful?
- Either phase digitally (BEACON) or mechanically?
- Parabolic dish every 1 km? Large at low frequencies!?

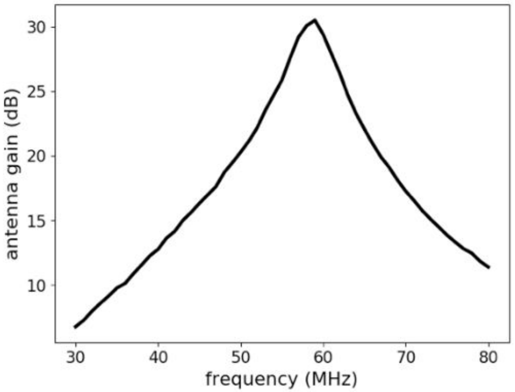
$$\theta_0 \approx \frac{1.22\lambda}{D} \text{ (in radians)} = \frac{70\lambda}{D} \text{ (in degrees)}$$

Approximation for small angles …

Wavelength at 60 MHz is 5 m,
10° HPBW would be 35 m dish!?
Yagi antennas? Or phasing ("on-line data transmission & processing")

High-gain broad-band low frequency antennas?

- Is that even possible? 35 m dishes certainly not.
- Maybe gigantic LPDAs installed high-up? :-/
- Do we really need the “broad-band” part? LOFAR effectively uses 58-62 MHz, very successfully.
- Maybe high-gain narrow-band is actually better than low-gain broadband, also in terms of narrow-band RFI susceptibility?
- Maybe couple 2-3 Yagi antennas at dedicated frequencies together?



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Possible Solutions for near-horizontal events

Challenges for near-horizontal radio detection

- External trigger is difficult due to low particle content
- Low signal strengths because radio signal gets diluted over large area
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Thoughts and possible solutions

- Self trigger required
- High detection threshold may be unavoidable; counterefforts:beamforming + machine learning
- High measurement precision of waveform and polarization may help to discriminate RFI
- Not well investigated: effects on phase in addition to amplitude relevant?
- Needs dedicated and well understood antenna design to minimize systematic uncertainties!

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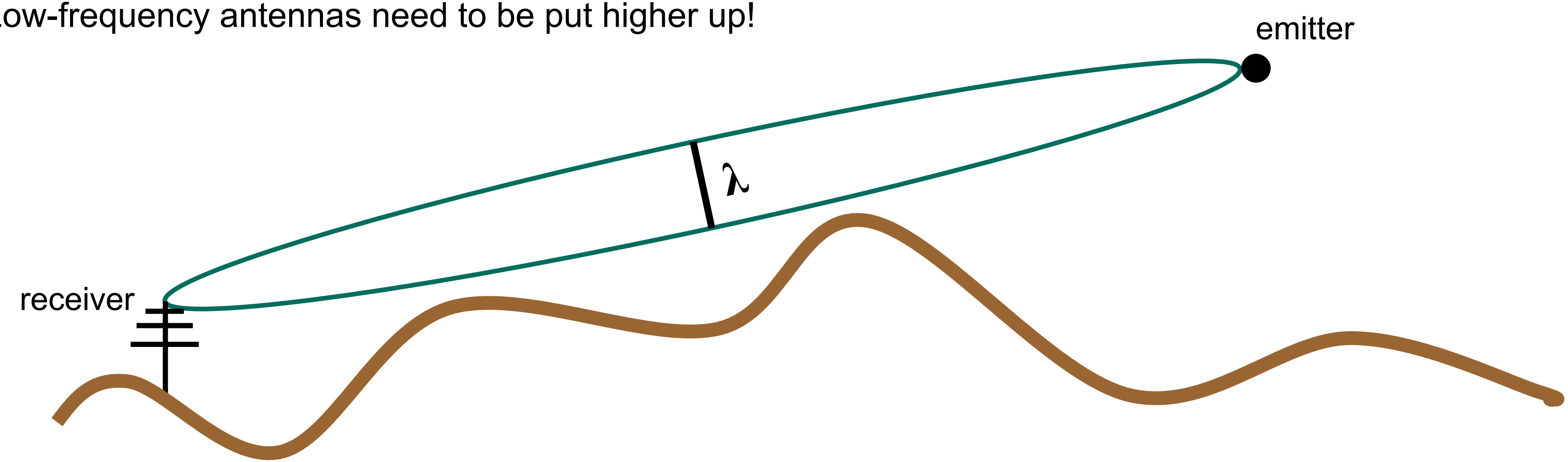
Ground relevant for propagation?

Rule of thumb: ground is relevant when pathlength with reflection differs by less than $\lambda/2$

Not clear: how accurate is this; what about non-pointlike antenna, what about non-point like emission?

Does it matter that air-shower wavefront has ~1 degree opening angle?

Low-frequency antennas need to be put higher up!



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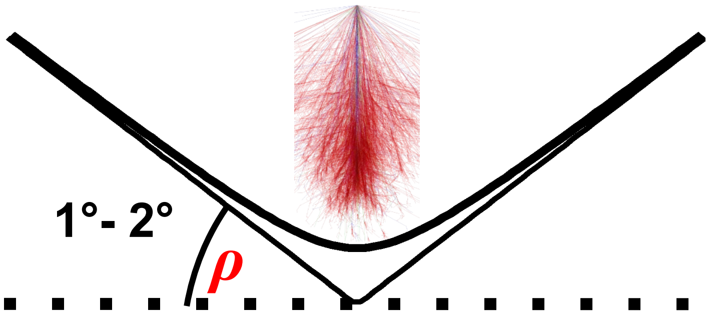
Antenna Pattern

Smooth Pattern preferable, even close to the horizon!

Assuming ~ 1 deg uncertainty of radio Poynting vector relative to antenna alignment

- angle of radio wavefront relative to shower axis
- uncertainties due to deployment, wind, temperature effects on mechanics, …

 Change of antenna gain within 1 deg should be less than 20% to achieve o(10%) energy uncertainty; also uncertainties on exposure, detection threshold, …



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Backup

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Noise consideration: Example SKALA v2

- system noise of 40 K exceeds Galactic Noise (sky) for frequencies larger than 400 MHz; thermal noise of sky (2.7 K of CMB) totally negligible; thermal noise of ground (~ 300 K) suppressed by antenna pattern
- if 300 K thermal noise of ground would be fully picked up by an antenna more sensitive to the horizon, than thermal noise would already dominate at frequencies larger than 150-200 MHz

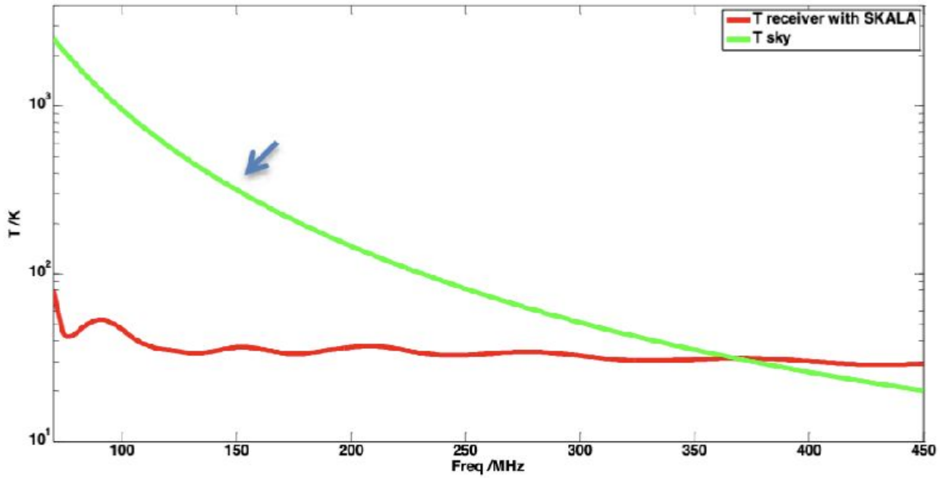
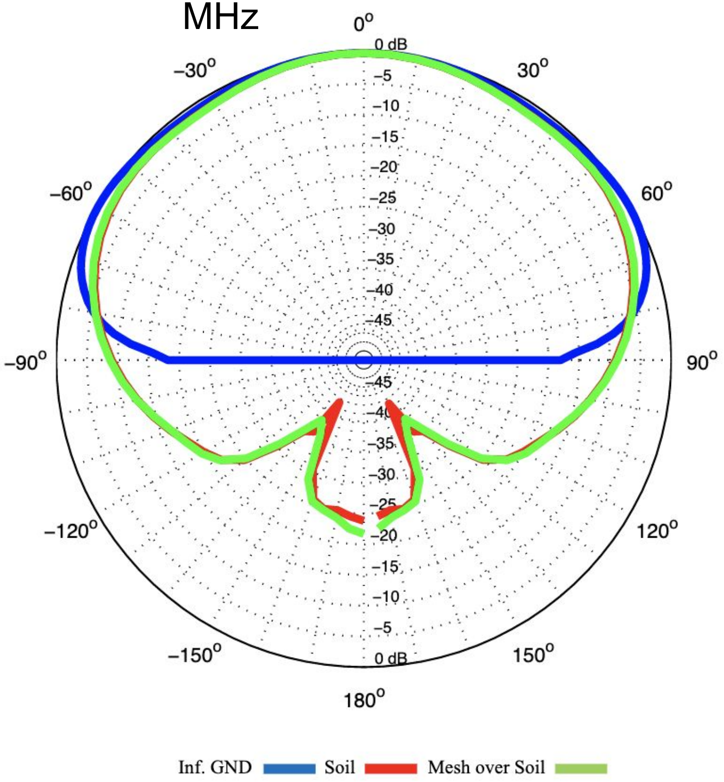


Fig. 9. Receiver noise temperature versus sky noise.

H-plane cut - 150 MHz



E. de Lera Acedo, N. Drought, B. Wakley and A. Faulkner, "Evolution of SKALA (SKALA-2), the log-periodic array antenna for the SKA-low instrument," *2015 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, 2015, pp. 839-843, doi: 10.1109/ICEAA.2015.7297231.

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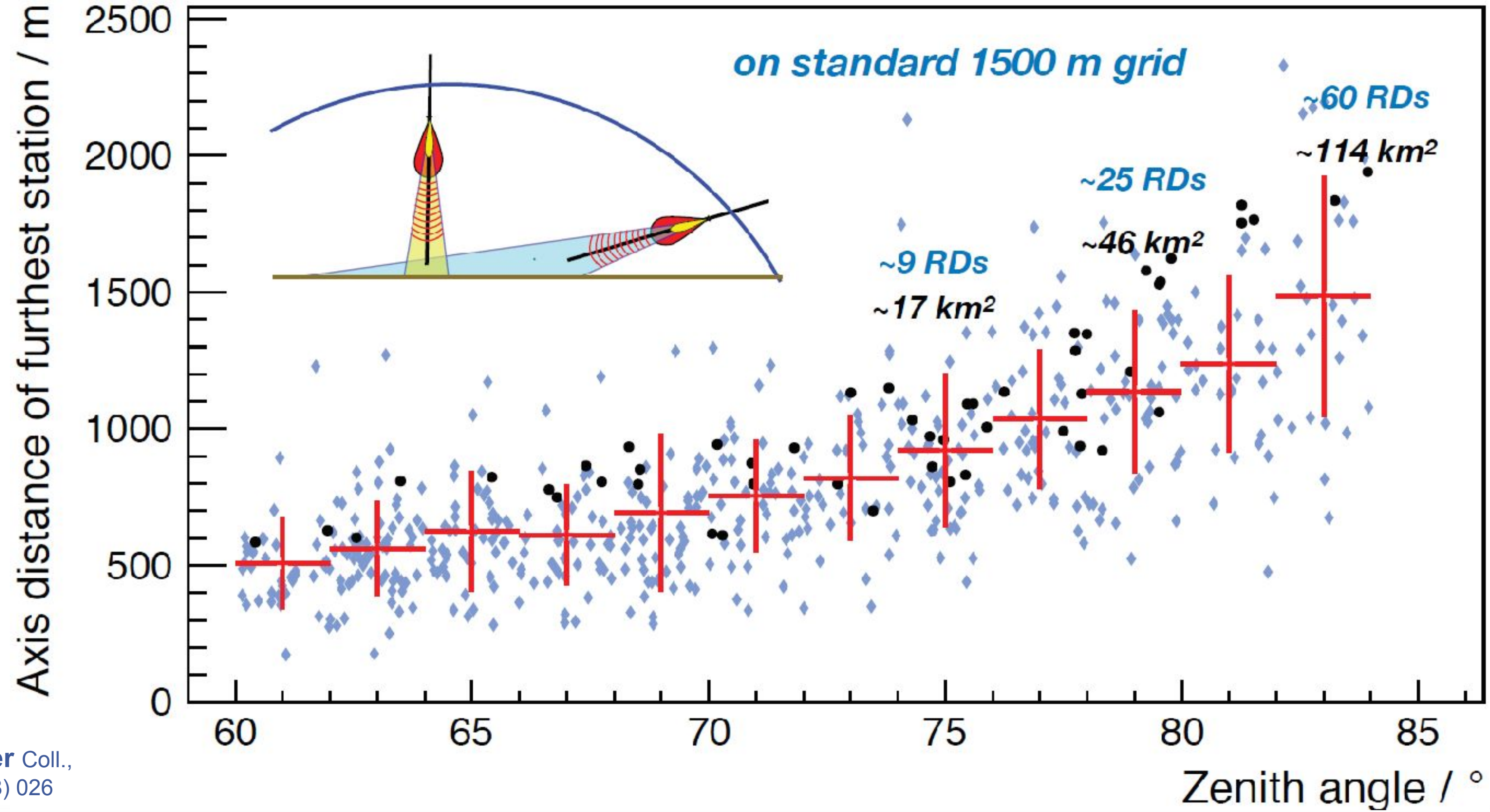
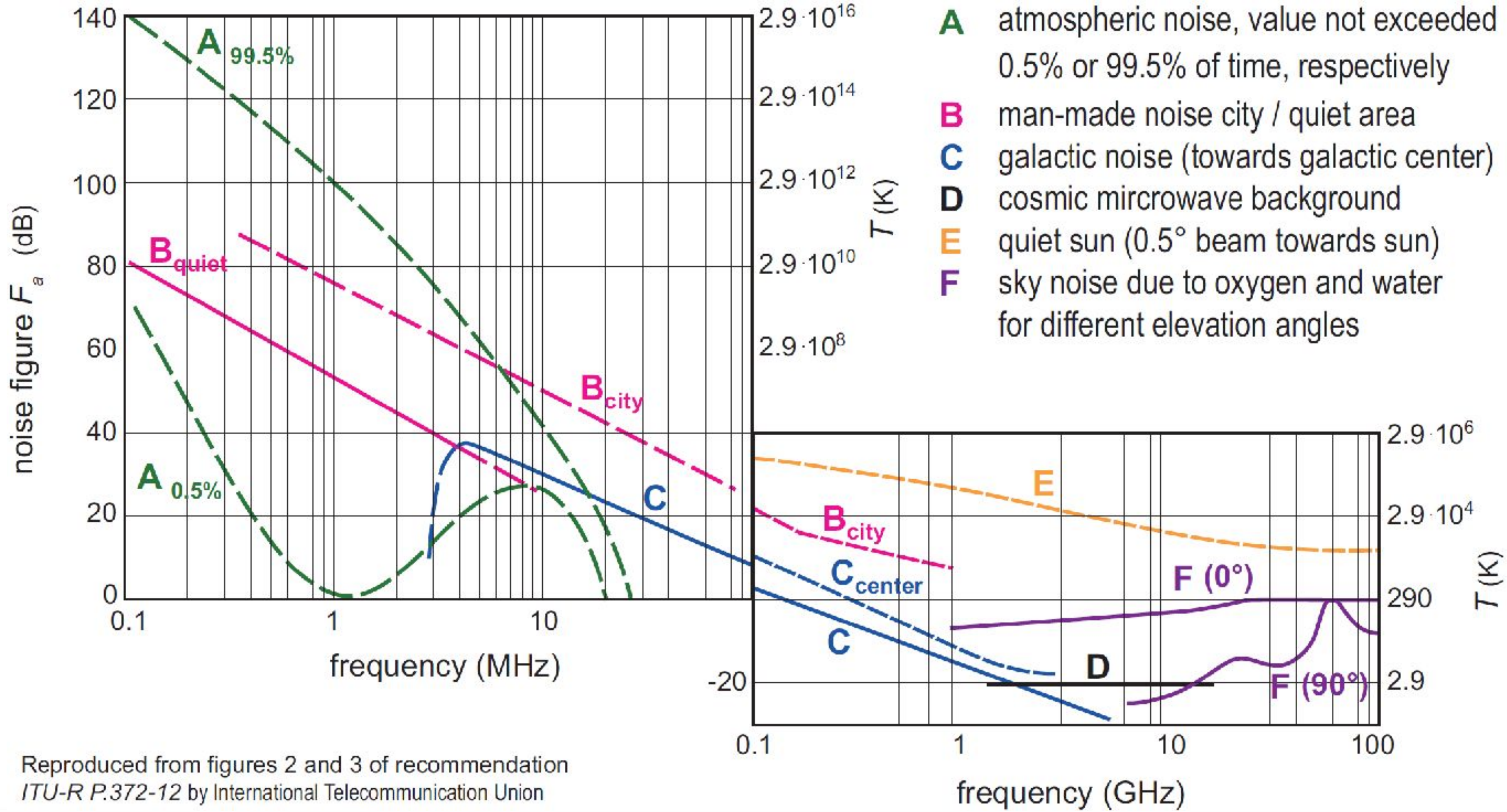
Huge radio footprints of inclined showers



Pierre Auger Coll.,
JCAP 10 (2018) 026



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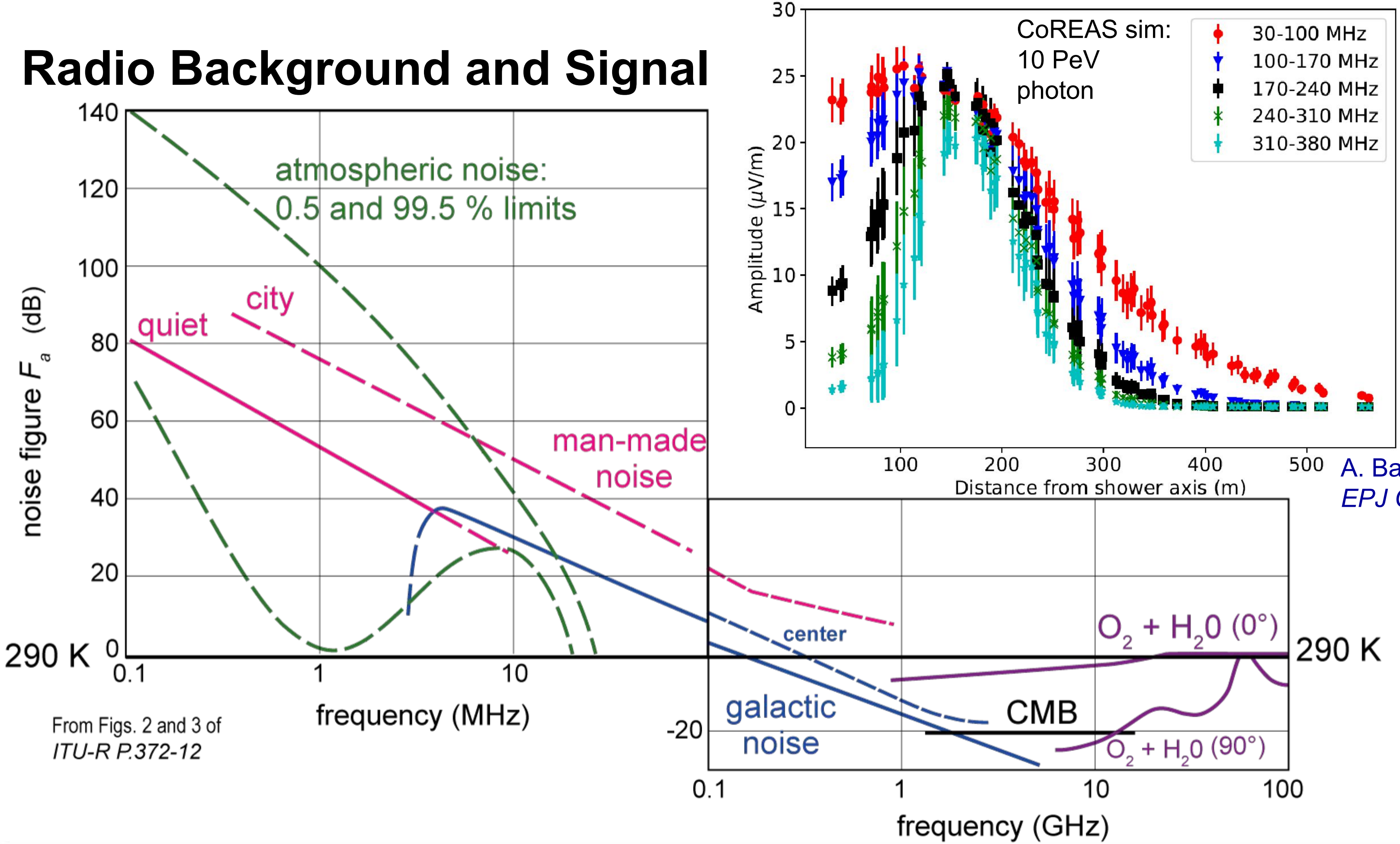
Radio Background and Signal



A. Balagopal V., et al.
EPJ C 78 (2018) 11

From Figs. 2 and 3 of
ITU-R P.372-12

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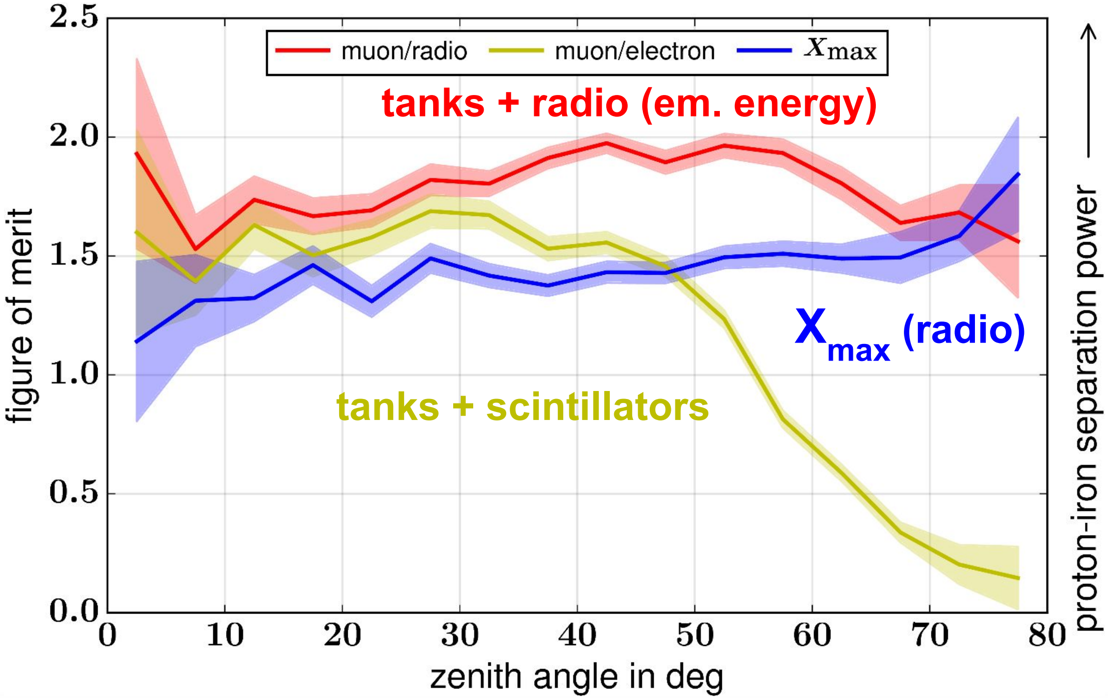
Radio + Muons: mass sensitivity at all zenith angles

- Enhance mass sensitivity for all zenith angles, in particular for inclined showers
- Complementary to depth of shower maximum, X_{max}



red + blue add complementary sensitivity

simulations for 1 EeV, **Auger** altitude, detailed simulations for IceTop needed

E. Holt, PhD thesis, simulation study for Auger, submitted to EPJ C

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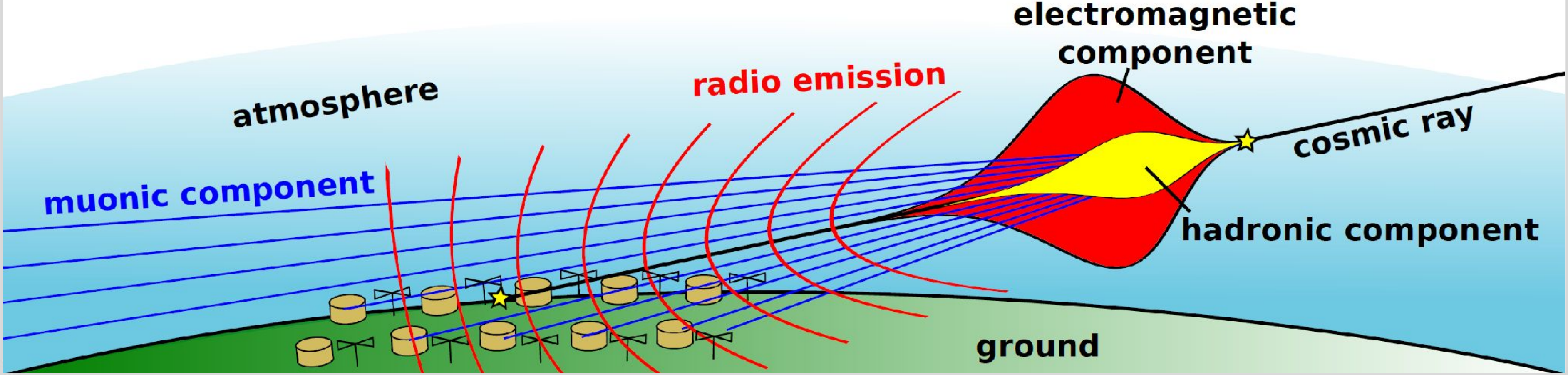
AugerPrime: Upgrade of the Pierre Auger Observatory

- Improved quality of surface detector:
  - scintillators + radio antennas
  - underground muon detectors
  - better electronics
- Enables per-event mass discrimination



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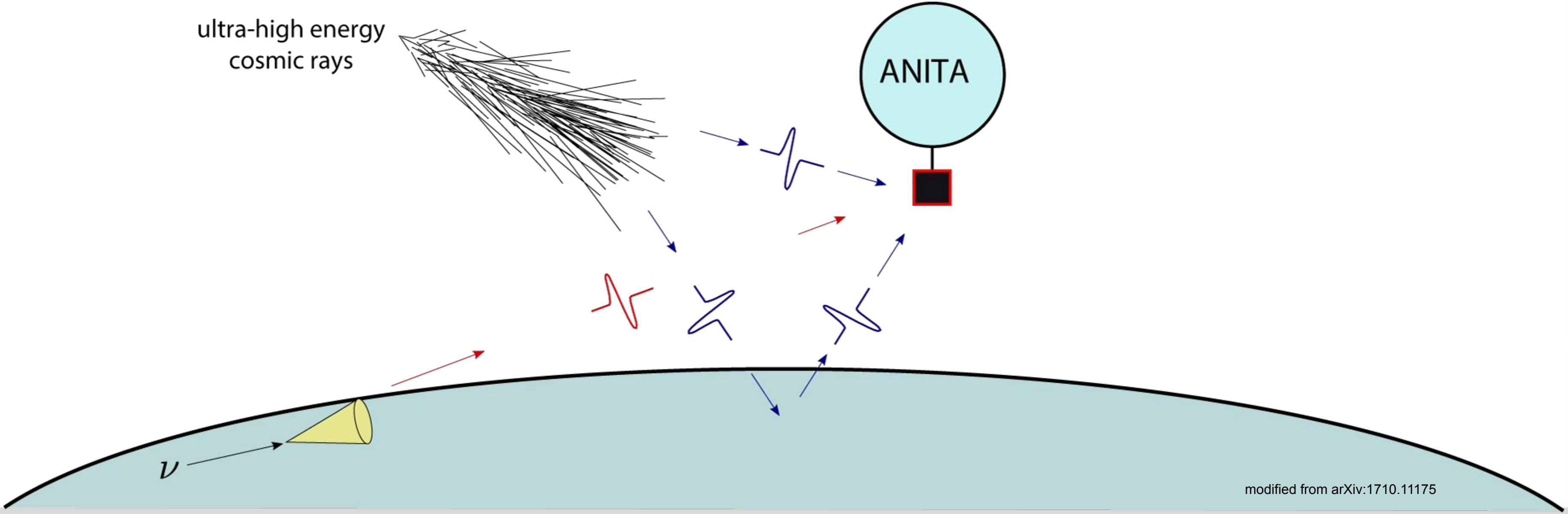
Sketch of ANITA

- Air-Shower detection on balloons and search for neutrinos.



modified from arXiv:1710.11175

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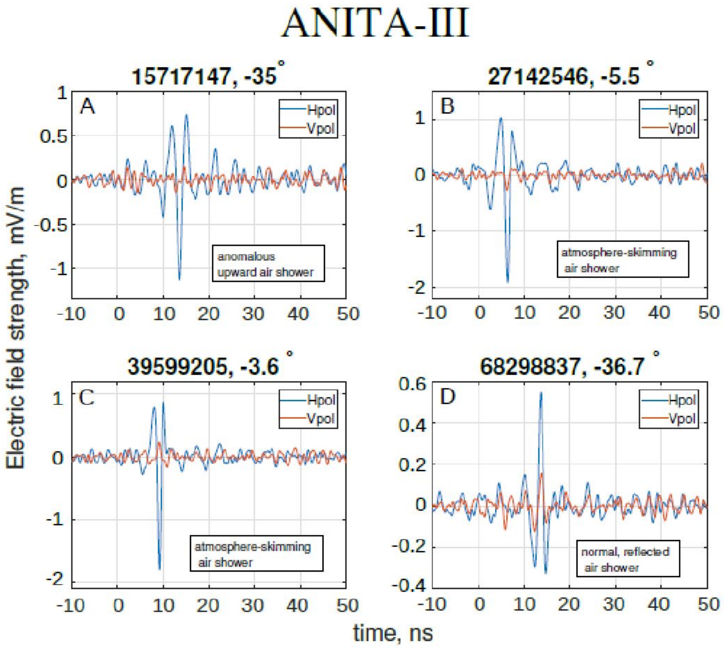
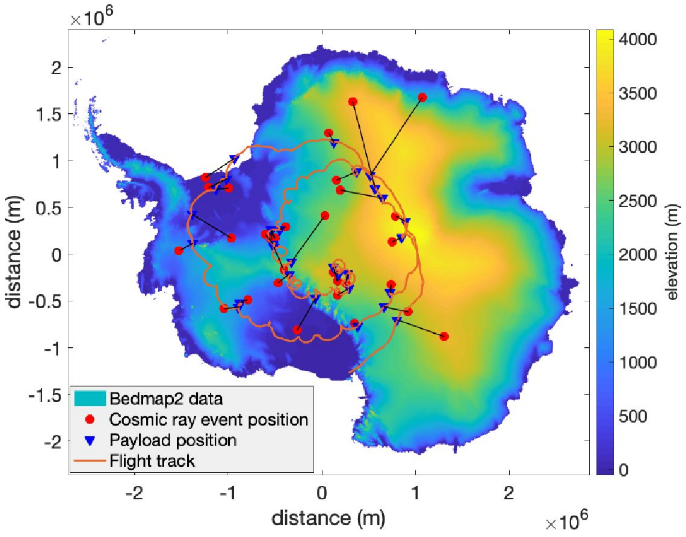
Cosmic-Ray detection with ANITA

- ANITA detects radio emission of highly inclined air showers
- Primary mission: Search for Askaryan emission from showers from the ice initiated by neutrinos

 see talk by Stephanie Wissels tomorrow



ANITA



ANITA Coll., arXiv.org: 2010.02892

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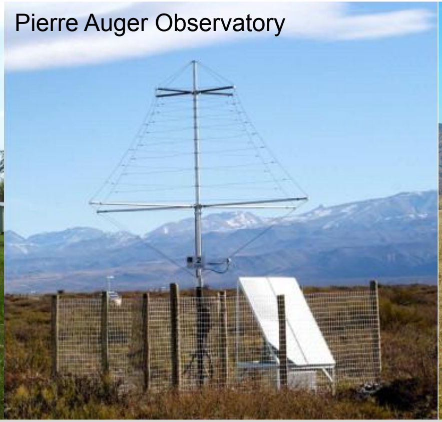

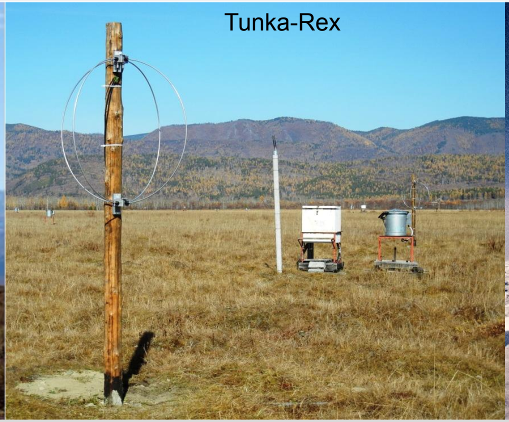

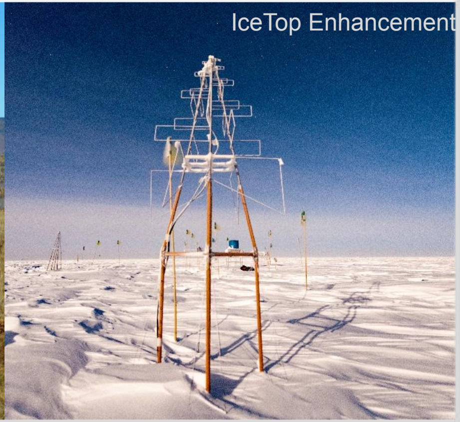

CHIME-like design?

Karlsruhe Institute of Technology

- 400-800 MHz, covering 200 square degrees with 1024 beams
- Too large at low frequencies?
- Can cover 2 Pi from a mountain top?
- Solid angle small (probability that beam hits antenna).
- CHIME has no moving parts; it consists of five (4?) parallel cylindrical parabolic reflectors, each 20m wide, 100m long and f/0.25. Feeds are spaced 30cm apart along each focal line. Signals are amplified and brought to a single custom digital correlator.