Complex analysis of Askaryan Radiation: UHECR and UHE-ν Reconstruction with Analytic Signals

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Summary

UHECR and UHE-ν Reconstruction with Analytic Signals

1. Introduction:
    - **A fully analytic Askaryan E-field** model in the time-domain [3]
    - Based on work begun with Prof. Amy Connolly [2]
    - Based on work begun by J. Ralston and R. Buniy [1]
    - Advantages: (i) extract UHE-ν cascade parameters by fitting model to raw voltage traces, (ii) fast and simple, (iii) analytic equations may be embedded as event filter
2. UHECR and UHE-ν identification:
    - **A fully analytic Askaryan voltage** model, time-domain [this work]
    - Equations for both voltage trace, and envelope of voltage trace
    - Verification with NuRadioMC: strong thermal background rejection, signal identification, and (rough) $\log_{10}(E_\nu)$ estimate
3. Correlation with Recent ARA observations of UHECR

UHECR Event Geometry for in the ARA Detector

UHECR Event Geometry for in the ARA Detector

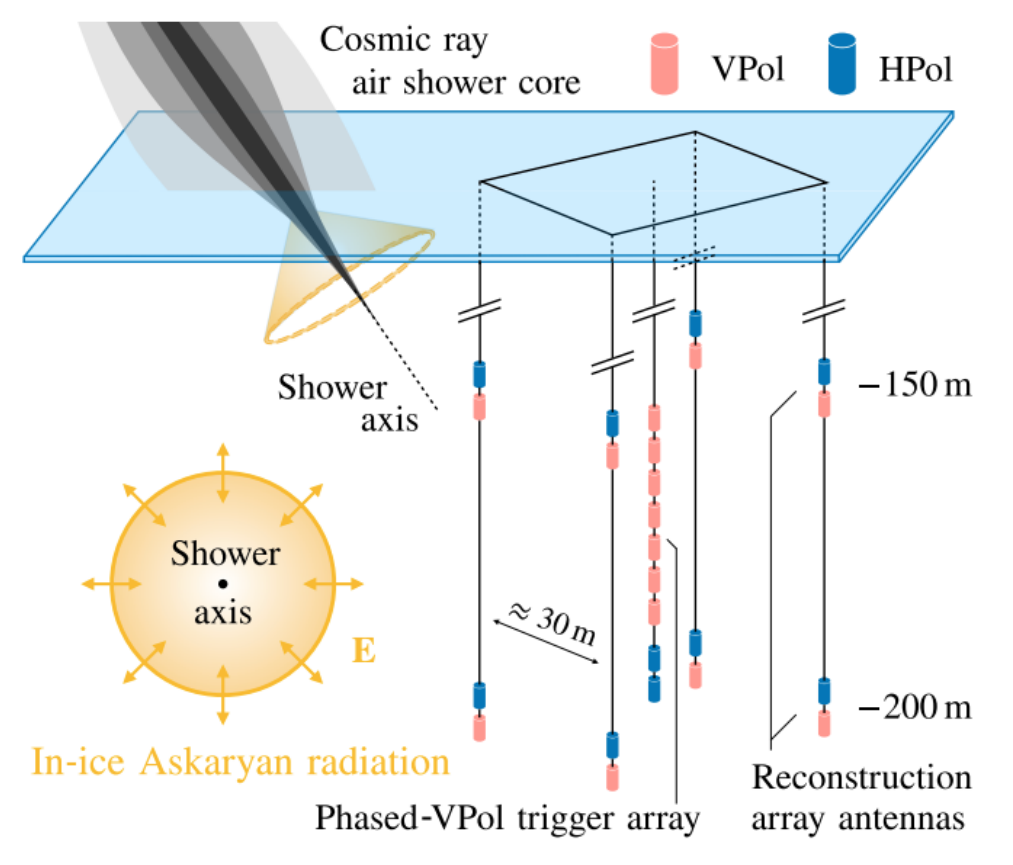

Figure 1: (Top right) UHECR cascade core interacting in ice. (Bottom left) ARA RF detection channels (Vpol and Hpol).

ARA detector schematic

- Askaryan component of the radiation
- Vpol and Hpol channels are dipole antennas
- E-field components are radial to the cascade axis
- Reference: `https://arxiv.org/pdf/2510.21104`

Notations and Definitions

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Askaryan electric field, $\vec{E}(r,t)$, [V m^{-1}]

$$r\vec{E}(t,\theta) = -\frac{E_0\omega_0 \sin(\theta)}{8\pi p} t_r e^{-\frac{t_r^2}{4p}+p\omega_0^2} \operatorname{erfc}(\sqrt{p}\omega_0) \tag{1}$$

Variable	Definition	Units
c	speed of light in medium	m ns^{-1}
r	distance to cascade peak	m
t_{r}	$t - r/c$	ns
θ_{C}	Cherenkov angle	radians
θ	viewing angle from cascade axis	radians
a	longitudinal cascade length (see [1, 2, 3])	m
n_{max}	max excess cascade particles (see [1, 2, 3])	none
E_0	$\propto n_{\mathrm{max}} a$ (see [1, 2, 3])	V GHz^{-2}
p	$\frac{1}{2}(a/c)^2\,(\cos\theta - \cos\theta_C)^2$ (see [3])	ns^2
ω_0	$\sqrt{\frac{2}{3}}(c\sqrt{2\pi}\rho_0)/(\sin\theta)$ (see [2, 3])	GHz
$\sqrt{2\pi}\rho_0$	lateral ICD width (see [2, 3])	m^{-1}

Table 1: Parameters relevant for $E(t)$.

Notations and Definitions

Askaryan *signal*, $\vec{s}(t)$, [V m^{-1}]

$$s(t) = -E_0 t e^{-\frac{1}{2}(t/\sigma_t)^2} \tag{2}$$

Detector *response*, $\vec{r}(t)$, [m ns^{-1}]

$$r(t) = R_0 e^{-2\pi\gamma t} \cos(2\pi f_0 t) \tag{3}$$

Bibliography

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