How Deep Learning and Differential Programming Accelerate Progress in Neutrino Astronomy

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Cosmic neutrinos provide a unique probe of the universe's most extreme environments, but their detection is extraordinarily challenging. However, the extremely small flux and cross-section of cosmic neutrinos make their detection extraordinarily challenging and demand the instrumentation of enormous target volumes.
In this colloquium, I will discuss how sparse arrays of radio detector stations, deployed in the polar ice sheets, can achieve unprecedented sensitivity to ultra-high-energy (UHE, $E > 10^{17}$ eV) cosmic neutrinos. I will explain the detection principle and will introduce the Radio Neutrino Observatory Greenland (RNO-G) - currently under construction - and outline the plans for the next-generation IceCube-Gen2 observatory at the South Pole.
I will also present my NuRadioOpt project, which leverages recent advances in deep learning and differentiable programming to enhance the performance of future radio detectors. In particular, real-time AI-based triggering may double the neutrino detection rate, while end-to-end detector optimization through differentiable programming promises substantial improvements in reconstruction accuracy and overall sensitivity.