SCIENCES &
BIOENGINEERING SCIENCES

The Research Group
Astronomy and Astrophysics

has the honor to invite you to the public defence of the PhD thesis of

Godwin Komla Krampah

to obtain the degree of Doctor of Sciences

Title of the PhD thesis:

Lunar Radio Detection of Ultra-High-Energy Cosmic-Rays and Neutrinos with LOFAR

Promotor:
Prof. dr. Stijn Buitink

The defence will take place on

Wednesday, December 20, 2023 at 16h in Promotiezaal D.2.01

The defence can also be followed through a live stream:
https://us02web.zoom.us/j/89378693218?pwd=K0llZ0JBZlVrNWRaVmRaaENsTGhCQT09

Members of the jury

Prof. dr. Nick van Eijndhoven (VUB, chair)
Prof. dr. Krijn de Vries (VUB, secretary)
Prof. dr. Frank De Proft (VUB)
Prof. dr. Olivier Martineau (Sorbonne Université, France)
Prof. dr. Simona Toscano (ULB)
Prof. dr. Didar Dobur (UGent)

Curriculum vitae

Godwin Komla Krampah obtained his bachelor (2015) and master's (2018) degrees in physics from the University of Ghana and Radboud University respectively. He later joined the VUB in 2018 as Ph.D. candidate working on the radio detection of ultra-high energy (UHE) neutrinos and cosmic rays interacting in the Moon. During these years he made a significant contribution toward the development a trigger algorithm for the future real-time observation. He also work on developing a Monte-Carlo code for simulating the effective aperture of UHE neutrinos interacting in the Moon. Using one-minute of data, he calculated the flux limits on neutrinos.

Abstract of the PhD research

Due to their low flux, understanding the origin and nature of ultra-high-energy (UHE) cosmic rays and neutrinos is a significant challenge. When these UHE particles interact with the Moon's regolith, they create particle showers, and the resultant charge asymmetry in the shower front leads to a short, coherent burst of radio emission. This phenomenon is known as the Askaryan effect. In the context of the NuMoon experiment, the primary objective of this study is to detect nanosecond radio pulses from these interactions on the Moon. The methodology, referred to as the lunar Askaryan technique, leverages ground-based radio telescopes and offers a substantial, effective aperture to enhance the likelihood of detection.

The LOw-Frequency ARray (LOFAR), operating within an optimal frequency range of 110-190 MHz for lunar signal detection, is employed to search for these pulses on the Moon's near surface. The success of this search necessitates an in-depth analysis of potential impediments, such as background noise and ionospheric effects, and the latter is shown in this work to reduce signal detection probability. In this work, we show how the ionospheric effect on the signal can be corrected and how to remove any radio frequency interference (RFI) present in the data. To further refine the search, a GPU-based algorithm was developed to simulate LOFAR's full data acquisition process. This process includes simulating a bandlimited Askaryan pulse, convolving this pulse with the antenna response, channelizing the signal using a polyphase filter bank, and beamforming pulses from multiple antennas to enhance sensitivity. With the simulation, the expected characteristics of both RFI-like and signal-like events in the beamformed data were investigated, leading to the design of an optimal signal or event differentiation technique.

A one-minute observation session was conducted using six LOFAR stations directed toward the Moon. A pulse search was carried out on the data that yielded no signal-like events. Consequently, a model-independent upper limit was established for UHE neutrino flux, utilizing a Monte Carlo simulation - developed in the context of this work - to evaluate the Moon's effective observational aperture for these elusive particles. This non-detection and the subsequent analytical results contribute to our ongoing efforts to unravel the mysteries of UHE cosmic rays and neutrinos.