VUB SCIENCES & BIOENGINEERING SCIENCES

The Research Group
High Energy Physics

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

Mitja Desmet

to obtain the degree of Doctor of Sciences

Title of the PhD thesis:

Synthesis Modelling the In-air radio Emission from particle cascades using Templates

Supervisor:
Prof. dr. Stijn Buitink
Co-supervisor:
Prof. dr. Tim Huege

The defence will take place on

Tuesday, October 14, 2025 at 4 p.m. in the U-residence, Green room (VUB Etterbeek campus, Pleinlaan 2, 1050 Elsene)

The defence can be followed via Zoom (Meeting ID: 813 3666 8849 - Passcode: 0vQzQG).

Members of the jury

Prof. dr. Steven Lowette (VUB, chair)
Prof. dr. Krijn de Vries (VUB)
Prof. dr. Ann Dooms (VUB)
Prof. dr. Ralph Engel (Karlsruhe Institute of Technology, DE)
Dr. Matías Tueros (Instituto de Física La Plata, AR)
Dr. Katharine Mulrey (Radboud Universiteit Nijmegen, NL)

Curriculum vitae

Mitja obtained his MSc in physics and astronomy from the VUB in 2021. In his master thesis he worked with lightning data from the LOFAR telescope. He remained a part of the LOFAR working group for his PhD, but shifting his focus towards simulating the radio emission from air showers.

As a PhD student at the IIHE institute Mitja organised seminars and tried to connect students with researchers. He also taught classes in the first bachelor program and supervised several bachelor and master theses.

Abstract of the PhD research

Astroparticle physics aims to understand the cosmos by studying the particles hurled toward Earth. Amongst these cosmic messengers are the elusive neutrinos and also γ-rays, which behave particle-like at higher energies. In this thesis I focus on the third member of the family however, the cosmic rays. These are atomic nuclei, accelerated to the highest energies known to hu mankind. Many different elements reach Earth, with energies as low as 10^{9} eV up to 10^{20} eV. Their origins still remain an unsolved mystery.

To find the answer, we need to measure the cosmic rays accurately. At the lower energies, satellite-based experiments can directly detect these particles. However, the flux of particles quickly drops with energy. Above $\sim 10^{14}$ eV we instead detect the extensive air showers triggered by the cosmic rays in the atmosphere. They emit various signals, including radio emission which is detectable over the background for energies above 10^{16} eV. The high duty cycle of radio arrays makes them an attractive option for cosmic ray physics.

To reconstruct the primary cosmic ray from the radio emission, we rely on simulations. The state-of-the-art simulation frameworks are Monte-Carlo based, calculating the radiation from each particle individually. While they significantly improved our understanding of the emission mechanisms, they suffer from one major drawback: their computation time. It scales with the energy of the primary cosmic ray, as well as the number of antennas in the simulation. This limits our analyses, but also negatively impacts the environment.

In this thesis, I present a novel, fast and accurate forward model, which can simulate the emission in a matter of seconds. My method, called template synthesis, uses a single Monte-Carlo simulation to synthesise the emission from other showers. It leverages semi-analytical expressions for the amplitude frequency spectrum, extracted from a large set of Monte-Carlo showers. Furthermore, it uses geometrical delays to adjust the phases. I explain how the model is constructed, by first considering a vertical geometry and then generalising to all others, up to 50° in zenith angle. From benchmarks I conclude that template synthesis has an accuracy of 6%, which is well within the uncertainties from other components in the signal chain. The benchmarks also show a small bias of 5%. Using SMIET, an open-source Python implementation of template synthesis that I created, I explore several use cases in which it can offer a significant computational benefit.