SCIENCES & BIOENGINEERING SCIENCES

The Research Group
High-Energy Physics

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

Xander Nagels

to obtain the degree of Doctor of Sciences

Title of the PhD thesis:

Beyond Standard Model Physics with Cosmological Phase Transitions and Their Gravitational Wave Signatures

Supervisor:
Prof. dr. Alberto Mariotti (VUB)
Co-supervisors:
Prof. dr. Alexander Sevrin (VUB)
Dr. Miguel Vanvlasselaer (Universitat de Barcelona, ES)

The defence will take place on
Monday, August 31, 2026 at 2:30 p.m.

VUB Etterbeek campus, Pleinlaan 2, Elsene,
In auditorium U residence.

The defence can be followed through Zoom.
(Meeting ID: 842 6100 1062 - Passcode: 1Mu5KG)

Members of the jury

Prof. dr. Stijn Buitink (VUB, chair)
Prof. dr. Krijn de Vries (VUB)
Prof. dr. Sophie de Buyl (VUB)
Dr. Jorinde Van De Vis (CERN, CH)
Prof. dr. Filippo Sala (Università di Bologna, IT)

Curriculum vitae

In 2022, Xander obtained his Master's degree in Physics and Astronomy from the VUB. He then began his PhD at the VUB in high-energy physics and gravitational waves, focusing on phase transitions in the early universe, investigating their dynamics and their consequences for dark matter generation, the observed baryon asymmetry, and stochastic gravitational-wave signals.

His work has led to several publications in peer-reviewed journals and been presented at international conferences. Alongside his research, he has taught “electrodynamics and special relativity”, and supervised bachelor's and master's theses.

Abstract of the PhD research

The Standard Model of particle physics provides a remarkably successful description of known fundamental particles and their interactions. However, it leaves several key questions unanswered, such as the origin of dark matter and the observed baryon asymmetry, motivating the exploration of physics beyond the Standard Model. Moreover, the detection of gravitational waves has opened a new observational window on the Universe, offering a unique opportunity to probe such new physics as it may have been realized in the early Universe, where the temperature was extremely high and all matter existed as a primordial hot plasma. As the Universe expanded, this plasma cooled and underwent a series of phase transitions.
In Beyond the Standard Model theories, these phase transitions can be first order, such that bubbles of a new phase form and grow, similar to bubble formation in boiling water. The interactions of these bubbles with one another and with the surrounding cosmic plasma leave behind traces in the form of gravitational waves. The strength and spectral shape of this signal depend both on the underlying high-energy physics and the bubble expansion velocity. If the latter is known, the observed signal can be used to probe former.

We therefore investigate several aspects of bubble dynamics in first-order phase transitions and how they address open questions in particle physics and cosmology. We argue that an additional criterion has to be introduced, beyond what is usually considered, to determine whether a bubble reaches a steady terminal velocity.
Moreover, understanding bubble dynamics is crucial, since rapidly expanding bubbles can play a key role in generating the baryon asymmetry and producing dark matter. We examine both cases and show that ultra-fast expanding bubbles can significantly enhance the resulting asymmetry and dark matter abundance, while also generating gravitational waves potentially detectable by future experiments.
Additionally, we find that with this production mechanism the resulting dark matter today can be heavy and have a non-vanishing velocity, features that would not arise without the presence of relativistically expanding bubbles.