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Unlocking the secrets of the universe: New discoveries in gravitational waves

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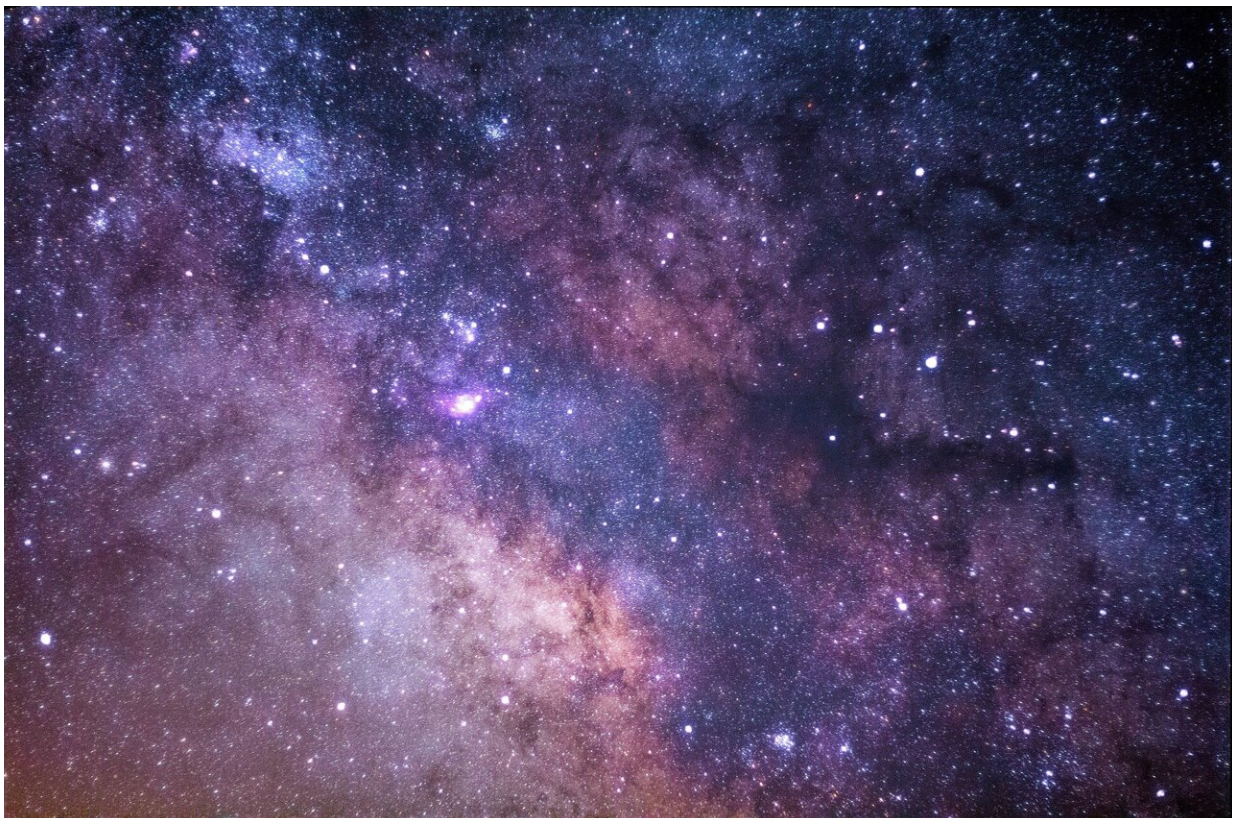

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A groundbreaking body of work led by Monash University physicists has opened a new pathway for understanding the universe's fundamental physics.

The work, featured in an international review published in *Progress in Particle and Nuclear Physics*, follows nearly a decade of work by scientists at the School of Physics and Astronomy in the Faculty of Science at Monash University.

Gravitational waves have only recently been detected for the first time, offering an exciting opportunity to delve into the mysteries of particle physics through first-order phase transitions (FOPTs) in the early cosmos.

FOPTs, occurring when new fundamental symmetries break down to the standard model, play a vital role in solving fundamental puzzles like the problem of cosmic matter, anti-matter, asymmetry or the problems of the dark sector, including dark matter and dark forces.

Researchers, including lead review author Ph.D. candidate Lachlan Morris, have embarked on a journey to review the process leading from particle physics models to observable GWs, highlighting the intricate steps involved.

"Our work serves as a comprehensive guide for particle physicists to explore the exciting realm of GW phenomenology," said Morris. "Understanding FOPTs is crucial for unraveling the mysteries of our universe."

The review details the intricate journey from particle physics models to observable GWs induced by vacuum decays during FOPTs.

The review, co-authored by Professor Csaba Balazs, sheds light on the complex process, covering steps like building effective potentials, analyzing transition rates, and predicting GW spectra.

"We're on the brink of a new era in gravitational wave astronomy," said

Professor Balazs. "The future holds immense potential for space- and ground-based detectors to reveal unseen phenomena, potentially emanating from FOPTs."

The review outlines the path from a particle physics model to GWs, which contains many specialized parts, including:

- building a finite-temperature effective potential in a particle physics model and checking for FOPTs
- computing transition rates
- analyzing the dynamics of bubbles of true vacuum expanding in a thermal plasma
- characterizing a transition using thermal parameters
- making predictions for GW spectra using the latest simulations and theoretical results and considering the detectability of predicted spectra at future GW detectors.

For each step the review emphasizes the subtleties, advantages and drawbacks of different methods, and reviews the state-of-the-art approaches available in the literature.

"This provides everything a particle physicist needs to begin exploring GW phenomenology," Professor Balazs said.

"As we commemorate nearly a decade since the revolutionary discovery of gravitational waves, the era of ground-based detectors has transformed our understanding of the cosmos. However, the upcoming era of space-based detectors promises even more extraordinary discoveries, potentially unlocking the secrets of new physics beyond the standard model."

More information: Peter Athron et al, Cosmological phase transitions: From perturbative particle physics to gravitational waves, *Progress in*

Particle and Nuclear Physics (2023). DOI: 10.1016/j.ppnp.2023.104094

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