Call for collaborators

Prof Andronikos Paliathanasis (Stellenbosch University) is inviting collaborators to join his research projects under two themes. The projects are suitable for MSc and PhD level, and may lead to publications, with opportunities to participate in both South African and international collaborations.

Theme A: Gravitational Physics and Cosmology

The recent cosmological data indicate that our universe is accelerating. The galaxies are “moving away” and that is happening rapidly. Dark Energy is considered to dominate to the universe, providing “anti-gravitational” force and drive the cosmic acceleration. Furthermore the data indicate that the dark energy has a dynamical behaviour.

The nature of dark energy is unknown, and there are various proposals in literature. The proposed models can be summarized in two large families (A) the dark energy models, where an exotic fluid source is introduced in Einstein’s General Relativity to explain the dynamics and (B) to models which modify Einstein’s theory of Relativity, and lead to a geometric description for the dark energy.

However, not all gravitational models are physical viable. There are theoretical and observational constraints for a dark energy model to be viable.

Proposed Research Projects:

1) **Explore the theoretical foundations of dark energy by analyzing various modified gravity and scalar field models.** Focus on identifying necessary conditions (e.g., absence of ghost modes, stability, correct cosmic evolution phases) for theoretical viability.

   Tools: Dynamical systems analysis, scalar-tensor reconstruction methods, field theory techniques. Differential geometry.

2) **Cosmological Constraints and Model Optimization.** Apply statistical methods to constrain dark energy models using current cosmological datasets (e.g., Supernovae, BAO, Cosmic Chronometers). Optimize model parameters and assess model selection using criteria such as AIC/BIC or Bayesian evidence. Determine new observational criteria for the viability of the model.

   Tools: Python-based statistical frameworks (e.g., Cobaya, MontePython), MCMC sampling.

3) **Data-Driven Cosmology: Reconstruction Techniques.** Utilize Gaussian Process Regression and Machine Learning (e.g., neural networks, symbolic regression) to reconstruct the Hubble function or the equation of state parameter directly from data and use these reconstructions to infer viable cosmological models. Study the implications for scalar field potentials or modified gravity functions.

   Tools: Machine learning, Bayesian methods, GP kernel design.

   Tools: Differential Geometry, Dynamical systems analysis, Python.

Theme B: Differential Equations Integrability and Solitons

Nonlinear differential equations appear in various branches of physics and applied mathematics. The integrability of such systems provides deep insight into their structure, enabling the determination of exact solutions, conserved quantities, and soliton-like behaviors.

Proposed Research Projects:

1) **Solitons and Topological Structures in Nonlinear Field Theories.** Solitons are a specific family of solution of nonlinear differential equations which have features of point particles. Are important for the description of physical phenomena. Investigate soliton solutions in nonlinear models such as the Korteweg–de Vries, sine-Gordon, and nonlinear Schrödinger equations. Explore Skyrmions and topological solitons in higher dimensions, with relevance to particle and condensed matter physics. Topological solitons and Skyrmions are of special interest in particle physics and in solid state physics.

   Tools: Differential equations, Algebra, Python, Geometry.

2) **Data-Driven Reconstruction of Dynamical Systems** . Use observational or synthetic data to reconstruct the governing equations of a nonlinear system. Identify hidden symmetries or conservation laws via symbolic regression or sparse identification techniques. Applications in Physics, Ecology, Biology, and others.

   Tools: Algebra, Python, Machine learning, AI Poincare.

About Prof Paliathanasis

View Prof Andronikos Paliathanasis' research interests and publications on his Google Scholar profile: https://scholar.google.gr/citations?user=ha0bqSoAAAAJ&hl=en

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