Exploring dark matter in the distant outskirts of the Milky Way with RR Lyrae variable stars and Deep Learning

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An international consortium of 15 institutes in is the final stages of building the state-of-the-art 4MOST wide-field spectrograph instrument to be commissioned at the European Southern Observatory, in Chile. Currently scheduled to begin in 2024, 4MOST will observe the spectra of tens of millions of sources in the southern sky over the next decade, providing unprecedented information on most areas of astrophysics. At the Observatoire astronomique de Strasbourg, we are leading 4GRoundS (PI: R. Ibata), the 4MOST survey to measure the radial velocities and chemical properties of the RR Lyrae variable stars detected by the Gaia space mission [1].

These RR Lyrae stars are very special as one can derive excellent distances for them from photometry, allowing the exquisite Gaia proper motions to be converted into physically-useful transverse velocities. Armed with the missing radial velocity, 4GRoundS will provide the community a dataset that will enable studies of the orbital structure of the halo and outer disk of our Galaxy, and allow realistic modelling of these components. It will also enable the identification of coherent dynamically-cold stellar streams [2].

The driving scientific ambition of the 4GRoundS survey is to reveal the six-dimensional phase space structure of the outer Galaxy using a uniquely powerful tracer. We aim to study the dark matter distribution and the kinematic response of star streams and the stellar halo to the clumpiness of the dark matter sub-haloes, effectively undertaking a seismological analysis of the Galactic halo. Together these analyses will map the mass of the Milky Way out to 100 kpc and test models of the dark sector.

Other obvious applications include a search for very low mass satellites of the Milky Way, investigating the global halo kinematic asymmetry due to the arrival of the Large Magellanic Cloud, studying the properties of the distant disk of the Galaxy, examining the bulge and inner halo, and attempting to quantify any spatial variations in kinematic coherence through the Milky Way's halo.

AIM of the thesis: There is a vast amount of work to be undertaken for 4GRoundS, preparing the survey, devising ways to optimally treat observations of variable stars (RRLyrae vary both in brightness and velocity over their ~0.6 day pulsation), writing the data processing software, perhaps to be included as part of the 4MOST pipeline, quantifying and correcting for the survey selection function, preparing scientific analyses of the observed populations (with dynamical models, including N-body models), etc. The Strasbourg PhD candidate would ideally contribute to several of these efforts and select one to lead in depth. The thesis advisor is particularly interested in using machine learning to devise optimization strategies, such as for information extraction from spectra and photometry, which will be crucial for 4GRoundS. He has extensive knowledge and interest in developing new deep learning algorithms for collisionless dynamics [3]. Ideally the student will share this fascination and be prepared to learn to build and to expand this powerful and rapidly-developing technology.

[1] Clementini et al. 2022, arXiv:2206.06278; [2] Ibata, R. et al. 2021, The Astrophysical Journal, Volume 914, 123 ; [3] Ibata, R. et al. 2021, The Astrophysical Journal, Volume 915, 5