The old Milky Way: a holistic approach for the accurate analysis of metal-poor stars

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Very metal-poor stars, those that have chemical elements in amounts that are 100 times or less than what is found in the Sun, are among the oldest stars in the Galaxy. Such old stars are fossils that can reveal details about the early stages of the Milky Way. In particular, the chemical elements in some of these extant metal-poor stars come from the explosion of the first stars to form in the Universe, i.e. the metal-free stars called Population III stars.

In this project, we will perform a novel study of the spectra of essentially all known very metal-poor stars. We aim to obtain an accurate characterisation of their atmospheric parameters (temperature and gravity) and chemical composition. With these results, we will conduct a meticulous study to reconstruct the properties of the first sources of chemical elements of stellar origin in the Universe. To achieve that goal, we will develop a holistic data analysis method that can be applied to spectra obtained by different instruments.

Determining accurate values of atmospheric parameters is a very challenging task. Recently, our research team at CAMK has developed a method to obtain surface temperatures and gravities that are accurate to 1%. The method combines state-of-the-art stellar models with precise parallaxes obtained by the Gaia mission of the European Space Agency. Unfortunately, this method cannot be applied to all very metal-poor stars as it needs high-quality data that can only be obtained for a restricted number of bright, relatively nearby stars.

Our strategy to overcome this difficulty is to implement and cross-calibrate multiple analysis methods. We will combine the use of spectroscopic, photometric, spectrophotometric, asteroseismic, interferometric, and astrometric data with state-of-the-art models when possible. This will create a general data analysis system that is capable of delivering accurate results even when not all types of input data are available. We will then analyse both new spectra and all useful data from archives of various telescopes and surveys.

Furthermore, we propose to take steps to prepare the methodology for the analysis of future observations of metal-poor stars from two new spectrographs, 4MOST and CUBES. These instruments will become available in the telescopes of the European Southern Observatory between 2024 and 2027. 4MOST is a multi-object spectrograph that will be installed at the 4m VISTA telescope at Cerro Paranal, Chile. It will simultaneously obtain spectra of ~2400 objects. CUBES is a single-object efficient near-UV spectrograph that will be installed at the 8m VLT, also at Cerro Paranal, Chile.

Our results will facilitate breakthroughs in our understanding of the first generations of stars. Moreover, this project will help to support the participation of the Polish and German partners in the two consortia developing the new instruments. This support is key to ensuring that the investment made in these new instruments will have a high-quality scientific return.