R-Process Chronometers in Ultra-Metal-Poor Halo Stars

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Nuclear chronometers have played an important role in the determination of the ages of the Solar System and our Milky Way Galaxy, thus providing important lower limits on the age of the Universe itself. Particularly useful are the long lived actinides ^{232}Th, ^{235,238}U, all of which are products of the r-process of neutron-capture synthesis. Earlier studies were based on models of galactic chemical evolution and the primordial abundances of Th and U in solar system matter.

Spectroscopic studies of extremely metal deficient stars have, over the past decade, made possible a quite different approach: age determinations for individual field halo stars and globular cluster stars from nuclear chronometers. Since such stars were formed in the very earliest epoch of star formation and nucleosynthesis in our Galaxy, their ages provide a measure of the age of the Galaxy (and a lower limit of the age of the Universe) itself. The relative abundance of Th to the stable r-process (only) element Eu was used as the appropriate chronometer. Theoretical calculations of r-process nucleosynthesis are required to determine the initial production ratios of the chronometric nuclei. Newer calculations use the observed solar system isotopic abundances to constrain these calculations [1, 2], motivated by increasing evidence to a scaled solar r-process abundance pattern in the oldest stars, at least for the heaviest elements (see Fig. 1).

However, as r-process calculations require nuclear physics input data of far unstable nuclei, in general not available from experiment, far reaching extrapolations are needed, which affect the production ratios and introduce uncertainties in the age determinations. Therefore it was proposed to replace the $_{90}$Th/$_{63}$Eu chronometric pair by abundance ratios of elements with less difference in the atomic numbers, as ratios between the actinides and 3rd neutron-capture peak elements ($_{76}$Os, $_{77}$Ir, $_{78}$Pt) or even $_{92}$U/$_{90}$Th. Whereas Th abundances have been determined for several halo stars, only upper limits had been reported for U. The recent determination of U abundances in CS31082-001 [3] and BD+17°3248 (see Fig. 1, [4]) now makes it possible to use the U/Th pair as a chronometer. We examine problems and constraints associated with the use of this chronometer such as uncertainties in the underlying atomic and nuclear physics in a forthcoming paper [5]. In addition, we show that even upper limits on U concentrations, together with Th abundances, can be utilized to impose lower limits on stellar ages. The potential significance of this approach lies in the fact that the weak U abundances, contrary to the higher Th abundances (due to the difference in half-lives),

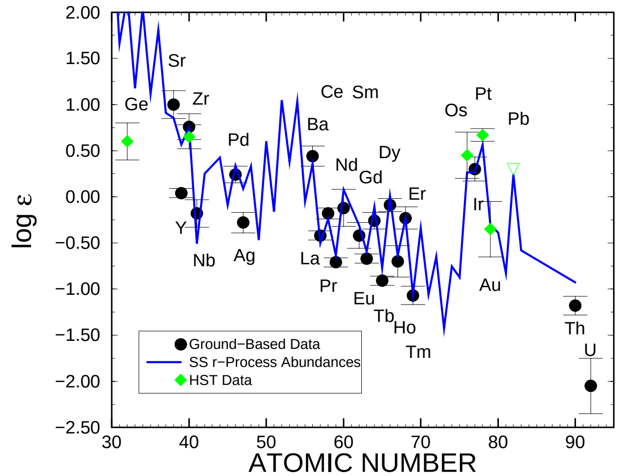

Figure 1: Neutron-capture element abundances in BD +17°3248 compared to a scaled solar system r-process abundance curve (blue line). The upper limit on the Pb abundance is denoted by an inverted triangle. Note also the Th and U detections.

will hardly become available for many halo stars.

R-Process nucleosynthesis finally is halted by the on-set of fission at mass numbers A≈260. We performed first calculations on the impact of β-delayed fission on the Th and U production [6, 7]. The β-delayed fission branchings were calculated in a self-consistent way with the new fission barriers of ref. [8] and the ETFSI-Q mass model. Further progress in the understanding of r-process chronometry is expected from the determination of Pb abundances with the Hubble Space Telescope. Direct comparison of the actinides and their stable decay product Pb should yield reliable age determinations. 40 orbits of HST are dedicated to the spectroscopy of CS31082-001 in the next cycle.

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