Prediction for the Pb abundance in ultra-metal-poor Halo stars

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Age determinations of geological or meteoritical samples can be performed by comparing the content of Th and/or U with their respective α-decay daughters $^{206-208}$Pb. Due to their long half-lives, ^{232}Th [14.05 Ga] and ^{238}U [4.468 Ga] are ideal cosmochronometers [1]. In the very early phases of nucleosynthesis, only r-process contributions from core-collapse supernova explosions of massive short-lived stars have to be taken into account. But, there are a number of problems to be solved. The old stars are found in the Galactic Halo quite distant from the Earth. In order to take high-resolution optical spectra, big telescopes are needed. Th and U are radioactive; hence since their production about one half of Th, all ^{235}U and 90% of ^{238}U have been decayed. The Pb isotopes at the end of the decay chains are stable, but optical transitions are in the UV which is strongly absorbed in the Earth's atmosphere. It is an advantage that the content of "metals" as Fe in these stars is typically a factor 10^3 lower than in the Sun, thus reducing blending by strong Fe absorption lines. Th can only be observed in the class of neutron-capture element enhanced ultra-metal-poor stars such as CS22892-052. For U and Pb, only upper limits of the abundances could be determined. Comparing the observed Th/Eu ratio with the production ratio derived from our r-process nucleosynthesis calculations, an age of (14.2 $\pm$ 3) Ga was determined [3]. The firm determination of a U abundance in a Halo star has been reported for CS31082-001 [4].

Recently, two groups of astronomers (with whom we collaborate since several years) have obtained long observation times on the Hubble Space Telescope in order to detect Pb in CS31082-001 and CS22892-052, respectively. The STIS spectrometer was specially adapted to UV observations not possible from the ground. Within this collaboration, we were asked to predict the Pb abundances in these stars. Tab. 1 lists abundances of $^{206-208}$Pb, ^{209}Bi, ^{232}Th and ^{235,238}U: 1) directly after the nucleosynthesis event and after β-decay of the extremely neutron-rich precursors in the r-process boulevard; 2) after the α-decays with $T_{1/2}$ in the order of several 10 Ma; and 3) after 13.5 Ga.

Tab. 2 lists predicted and observed values for elemental abundances. The isotopic abundances of Tab. 1 were scaled down to the metallicity of the stars by fitting the rare-earth elements. In the case of CS31082-001, the "actinide boost" [4, 5] was determined from $_{72}$Hf. All predicted abundances for Z$\geq$72 were multiplied by a factor 2.4. With this scaling, there is nearly perfect agreement between the predicted and observed values for Th and U. The situation for Pb is , however, less satisfactory. The observed value of (-0.03$\pm$0.15) dex [6] for CS22982-052 is slightly above our prediction. On the other hand, Plez et al. reported a Pb abundance for CS32081-001 of (-0.55$\pm$0.15) dex [7], much lower than our predictions. Their value is even lower than the fraction of the lead synthesized directly in the SN explosion (-0.25 dex). Therefore, one may ask where is the Pb from the α-decay chains (-0.36 dex) from Th and U observed in this star? Abundances similar to those shown in Tab. 1 have been reported in [8]. We therefore conclude that the strong discrepancy between predicted and observed Pb abundances in CS32081-001 cannot be caused by the underlying assumptions on nuclear structure.

Table 1: Isotopic abundances from r-process nucleosynthesis calculations [2] in units of Si$\equiv10^6$. In the first column are listed abundances after β-decays directly following the explosion. Abundances after α-decays of "short-lived" nuclei as the ones in the Np-chain are tabulated in the second column, and after 13.5 Ga in the third one.

	Abundances after		
Isotopes	β-decays	"short-lived" α-decays	13.5 Ga
Pb-206	0.0217	0.1426	0.1637
Pb-207	0.0182	0.1075	0.1447
Pb-208	0.0287	0.1245	0.1443
Σ PB	0.1122	0.3746	0.4527
Bi-209	0.0152	0.1013	0.1013
Th-232	0.0183	0.0415	0.0217
U-235	0.0091	0.0368	
U-238	0.0075	0.0230	0.0019

Table 2: Predicted and observed elemental abundances for two Halo stars in [dex] units. The observed values except for Pb are taken from [3] for CS22892-052 and [4] for CS31082-001. The Pb valus are from [6] and [7], respectively.

	CS22892-052		CS31082-001	
Element	pred.	obs.	pred.	obs.
Hf	-1.21	-0.98	-0.61	-0.59
Os	-0.26	0.06	0.33	0.43
Ir	-0.23	0.00	0.36	0.20
Pb	-0.23	-0.03	0.36	-0.55
Bi	-0.88		-0.29	
Th	-1.55	-1.57	-0.96	-0.98
U	-2.61	<-2.3	-2.02	-1.92

References

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