Actinides and the source of cosmic rays

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Supernova shocks provide the energy for the acceleration of Galactic cosmic rays (ranging up to the actinides), but the source material as well as the acceleration mechanism are open questions. The similarity between ultraheavy cosmic rays (UHCR) and the interstellar medium (ISM) suggested that they may be accelerated out of the well-mixed ISM. But, since most of the heavy elements are ejected into the ISM by supernovae (SN) (which are clustered in space and time), the relative abundance ratios will not differ between these ejecta and the well-mixed ISM. However, the UHCR abundances of the actinide elements, Th, U, Pu and Cm, can provide critical constraints on the major sites of their acceleration and metallicity, as well as on the time scales involved [1]. The most probable source for the UHCR are the about 20 SN explosions which took place over the last 10 MYrs in the close-lying Scorpius-Centaurus OB associations. The shock waves of the first SNs blew an enormous bubble in the ISM, the local superbubble, facilitating the propagation of the ejecta from the later SN [2].

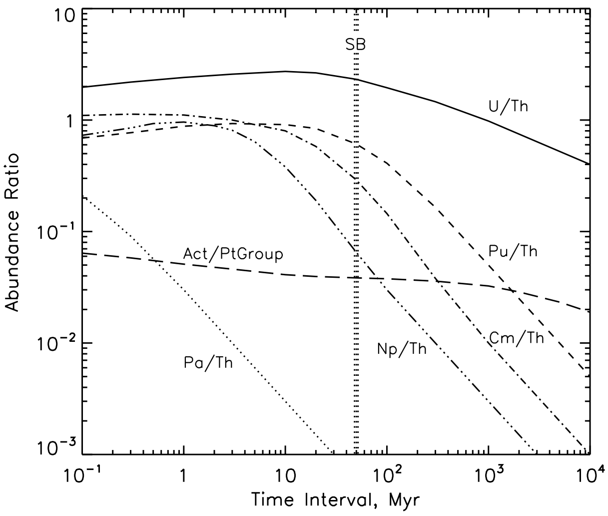

Figure 1: Mean actinide abundance ratios from r-process yields in core-collapse supernova ejecta averaged over various time intervals. The typical cosmic-ray acceleration time span in the supernova-active cores of superbubbles of roughly 50 Myr is indicated by the dashed line (SB).

The Mainz group has calculated the r-process yields in core-collapse SN within the "waiting-point approximation" [3, 4, 5]. From these yields the actinide abundances in the cosmic rays averaged over time following the SN explosions are predicted (see, Fig. 1).

Using standard Galactic chemical evolution methods, the expected actinide abundances in the present day ISM and in the SN-active cores of superbubbles as a function of their ages and mean metallicity resulting from dilution

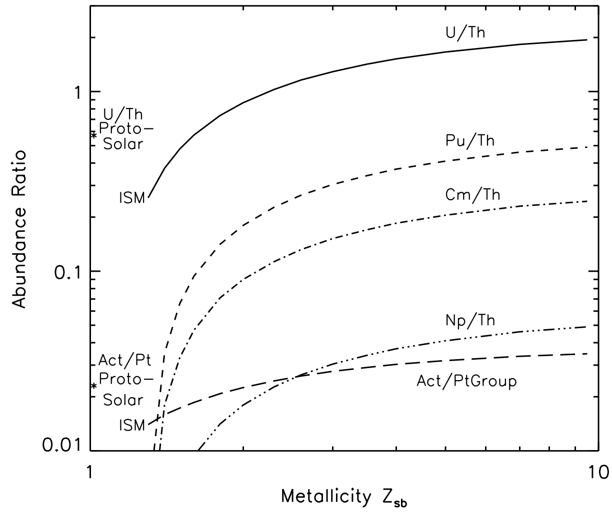

Figure 2: Expected cosmic-ray actinide abundance ratios as a function of superbubble core metallicity. Also indicated are the estimated U/Th and Actinide/Pt-Group (Z = 75 to 79) ratios in the current interstellar medium (ISM) and in the supernova-enriched proto-Solar material.

with interstellar clouds are predicted (see, Fig. 2). The current measurements of the actinide/Pt-group ratios [6] and preliminary estimates of the UPuCm/Th ratio in cosmic rays [7] are consistent with the predictions if superbubble cores have metallicities of 3 times solar.

Future measurements of the abundance ratios with improved statistics will help to solve these questions. First results of experiments performed on the MIR space station (ECCO [8]) and with ultra-long duration balloon flights (TIGER [9], which serves as an engineering model for the future Heavy Nuclei Explorer mission) are promising. In addition to meteoritic material and optic spectroscopy of stars, a new window to extra-solar matter is opened.

References

[1] R.E. Lingenfelter et al., submitted to Ap. J.
[2] N. Benitez et al., Phys. Rev. Lett. 88 (2002) 1101
[3] K.-L. Kratz et al., Ap.J. 403 (1993) 216
[4] B. Pfeiffer et al., Z. Phys. A357 (1997) 235
[5] B. Pfeiffer et al., Nucl.Phys. A693 (2001) 282
[6] A.J. Westphal et al., Nature 396 (1998) 50
[7] J. Donnelly et al., 27th ICRC, Hamburg, 2001
[8] A.J. Westphal et al., Adv. Space Res. 27 (2001) 797
[9] J.T. Link et al., 27th ICRC, Hamburg, 2001