A Signal of a Close Supernova 3 Myr ago

K. Knie, A. Arazi, T. Faestermann, W. Hillebrandt [a], G. Korschinek, G. Rugel, A. Wallner, and C. Wallner
[a] Max-Planck Institut für Astrophysik, Garching

There are several indications for one or even more supernova(e) (SN) at rather close distance to the solar system during the last millions of years. These hints come from rather different fields in science, like paleobiospheric studies [1,2], theoretical models about the origin of the local hot bubble [3] and studies of the extreme ultraviolet radiation in the solar vicinity [4,5]. A unique and clear indication could be long lived radioisotopes which are ejected with the debris of a SN and spread over the Earth, if they are not formed otherwise or only in very small quantities. In a previous publication [6,7] we reported for the first time an indication for SN released ^{60}Fe on Earth. This motivated us to obtain more detailed information concerning time dependence and also total amount of deposited material. To this end, the investigation of deposits well-resolved in time is mandatory.

^{60}Fe is produced in significant amounts by core collapse SNe. The ejected debris might travel as far as 50 pc, but also distances beyond 100 pc are possible as the density of the interstellar medium (ISM) can vary by more than three orders of magnitude. The natural occurrence of ^{60}Fe on Earth is far below an expected SN induced signal [6], the half-life of 1.49 Myr long enough to cover several Myr before it fades away, and, with accelerator mass spectrometry (AMS), we have an ultra-sensitive method to determine ^{60}Fe/Fe ratios down to a level of 1×10^{-16} [8]. Considering these arguments, we believe that ^{60}Fe is a unique indicator for the detection of SN debris on Earth.

Hydrogenetic deep-ocean ferromanganese crusts offer an ideal reservoir for detecting such a signature. We chose a crust originating from the equatorial Pacific at a depth of 4830 m. It's growth rate of only 2.5 mm/Myr, deduced from the ^{10}Be concentration [10], was constant within the last 6 Myr. In order to get a clear and time-resolved signal, 22 layers between 1 and 2 mm thickness were milled out, corresponding to a total time span from 0 to 13 Myr [9]. The ratios of ^{60}Fe to stable Fe were determined with accelerator mass spectrometry at the Munich MP-Tandem accelerator. Since the ^{60}Fe/Fe ratios were extremely low, the layers have been analyzed repeatedly (up to 36 times) in six separate runs to reduce statistical and systematic errors. To be able to definitely exclude contaminations during sample preparation, different AMS samples have been independently prepared from each layer. Fig. 1 shows the results of the AMS measurements of the respective layers. Only the layers at 2.8 and 3.6 Myr show a clear signal ($> 2\sigma$ above background) peaking at T = (3.0 ± 0.4) Myr. The integral of a gaussian fit corresponds to an ^{60}Fe fluence $\Phi_{60}^{c} = (4.3 \pm 1.7) \times 10^{6}$ at cm^{-2}, if one corrects for radioactive decay.

It has to be noted, that the Φ_{60}^{c} is not equal to the ^{60}Fe amount introduced into the water column above the crust. However, in analogy to the method described in [6] the uptake factor can be estimated to $U_{Fe} \approx 0.6$ % using our determination of the crust's ^{53}Mn concentration. Besides the uptake correction one has to take into account that ^{60}Fe is spread over the Earth's surface, which has an area of four times its cross section; hence the local interstellar fluence $\Phi_{60}^{LIS} = 4\Phi_{60}^{c}/U_{Fe} = 3 \times 10^{9}$ at cm^{-2}.

How does this signal compare to a possible nearby SN? Woosley and Weaver [11] have calculated that a type II SN of solar metallicity in the mass range between 11 and 25 solar masses ejects on average 3.1×10^{-5} solar masses of ^{60}Fe, corresponding to 6×10^{50} atoms. Distributed over a sphere with a radius $R = 40$ pc ($A = 1.9 \times 10^{41}$ cm^{2}) the surface density equals Φ_{60}^{LIS}.

If one allows for an uncertainty of a factor three for the experimental value of Φ_{60}^{LIS} and uses 50 % as an estimate for the uncertainty of the expected signal, the value of 40 pc for the distance of the SN explosion is uncertain by a factor of two. Possibly, the origin of the detected SN is either the B1 subgroup of the Pleiades [12] or the LCC subgroup of the Scorpius-Centaurus OB association [13]. Both stellar groups, which are expected to have a SN rate of roughly 1 Myr^{-1}, have been traced back to solar distances of 100 pc and below.

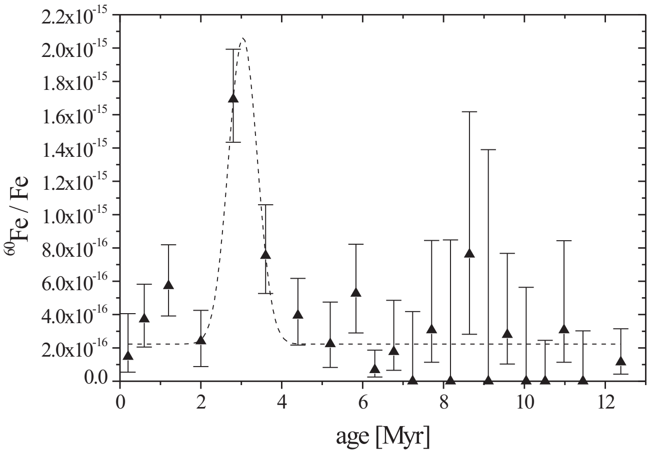

Fig. 1: ^{60}Fe/Fe ratios versus the age of the respective layer in the ferromanganese crust. The data are not corrected for radioactive decay and background. The error-bars correspond to a confidence level of 68.3 %

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