Near-Earth Supernovae Probed by Deep-Sea Deposits of Radioactive ^{60}Fe

Sara Ayoub

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Abstract

After decades of lack of precision in estimating the frequency of supernovae and their effects on our planet and the interstellar medium, Wallner et al. were able to use the isotope ^{60}Fe as a chronometer, through accelerator mass spectrometry, to identify two major eras, one 1.5–3.2 million years ago and another at 6.5–8.7 million years ago, during which there was a significant influx of that isotope onto Earth. They analysed deep-sea archives from all major oceans for ^{60}Fe deposition, and the results indicated that several supernovae may have exploded within 100 parsecs of Earth during those two eras. For more than half a century, scientists have speculated that close enough supernovae could have affected the planet, possibly contributing to mass extinctions or climate change. Interestingly, these two periods coincide with a strong increase in ^{3}He and temperature change at about 8 Myr ago, and a temperature drop during the Plio−Pleistocene transition at about 3 Myr ago.

Problems:

➡ Lack of precision estimating frequency of supernovae

1990s radionuclides can be used to probe these events but isotopes were problematic :

- ^{10}Be also produced by radiation in atm.
- ^{144}Pu background contamination

1999 detection of ^{60}Fe in FeMn crusts

2015 new milestone measuring half-life of ^{60}Fe

➡ 2.50±0.12 Myr
rules out the older result of 1.49±0.2 Myr[1]

➡ important chronometer for astrophysical applications in the million-year time range

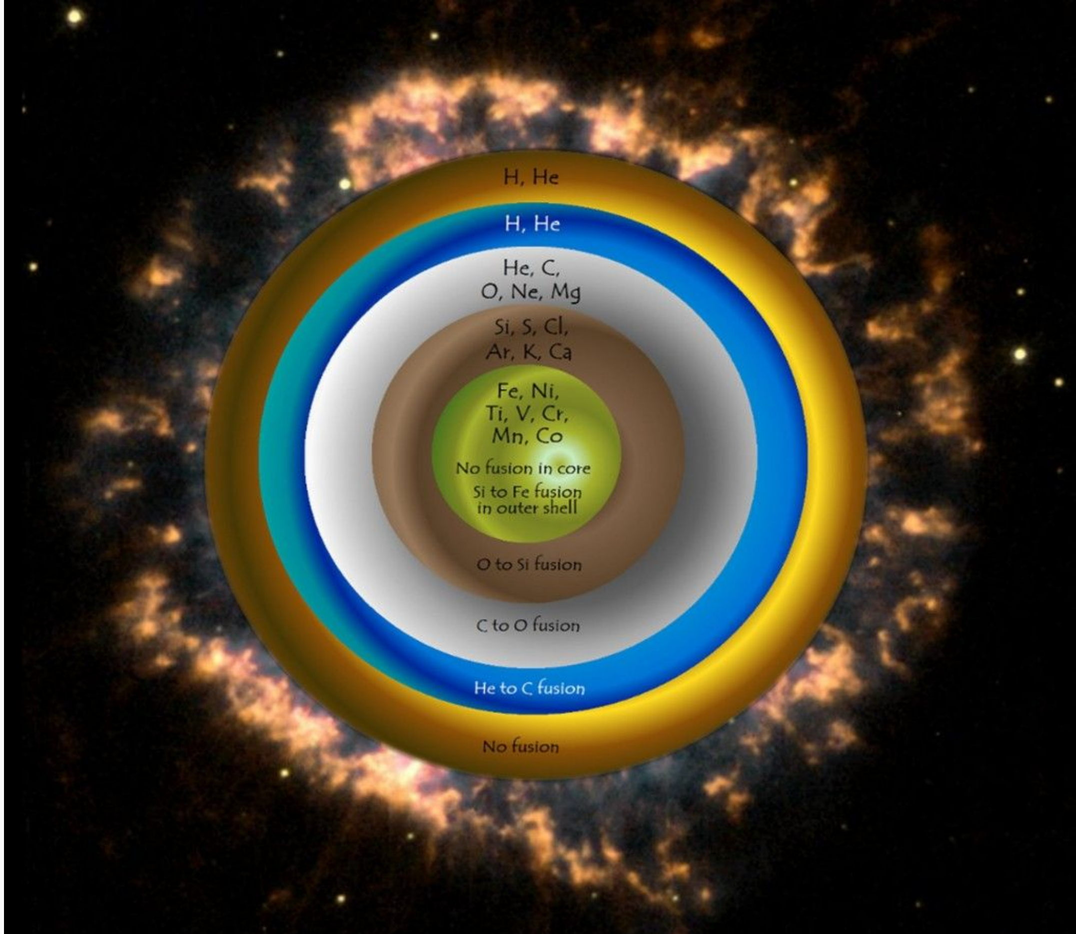

Fig1: Layers of nucleosynthesis products in a massive star.

April 2016 **Wallner et al using AMS^2:** ^{60}Fe levels averaging at 40 times background levels!

Fig2: Locations for new and previous deep-sea ^{60}Fe archives.

Deep-sea archive	Cores / pieces	Location	Time period studied	Individual samples	Radionuclides measured
Sediment cores	4	Indian Ocean	0, 1.7–3.1, >4.0 Myr	52-89	^{60}Fe, ^{26}Al, ^{10}Be
FeMn crusts	2	Pacific Ocean	0 – 11 Myr	31	^{60}Fe, ^{10}Be
FeMn nodules	2	Atlantic Ocean	0 – 5.4 Myr	8	^{60}Fe, ^{10}Be

Table1: Summary of the three different archives.

Images: Supplementary information, Wallner, A. et al. Phys. Rev. Lett. 114, 041101 (2015)

120 ocean-floor samples spanning the past **11 Myrs**

➡ Separation of ^{60}Fe from other isotopes using the **Heavy-Ion Accelerator** at ANU

➡ Most ^{26}Al and ^{10}Be is from cosmic-ray bombardment in the atmosphere

➡ Age of cores determined by decay of ^{10}Be and ^{26}Al using AMS

➡ Determination of atom ratio $^{60}Fe/Fe$

➡ Challenging to remove ^{60}Ni interference at these low levels (~10^{-15}):

- gas-filled magnet blocking ^{60}Ni from entering the final particle detector
- multielectrode ionization chamber that determines energy, rate of energy loss and position to separate residuals

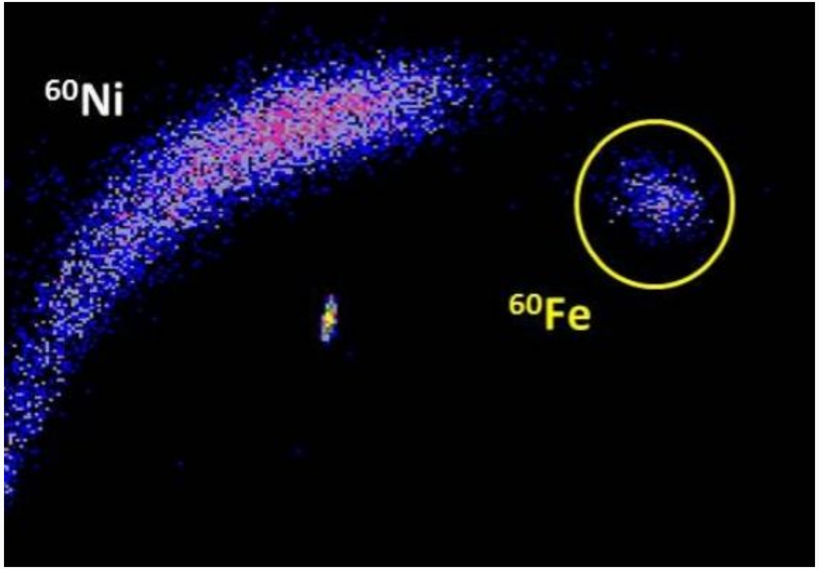

Fig3: Separation of ^{60}Fe from the isobar ^{60}Ni. Spectra with a separation of ^{60}Ni and ^{60}Fe obtained for a reference material with $^{60}Fe/Fe$~10^{-12} . Demonstrates single atom counting of ^{60}Fe at the ANU.

Image: Supplementary information, Wallner, A. et al. Phys. Rev. Lett. 114, 041101 (2015)

Sediment core	Sample category	No. of samples	Time period (Myr)	^{60}Fe counts detected	^{60}Fe/Fe isotope ratio (10^{-15} at/at)
50-02	surface layer	2	< 0.2	1	0.05±0.05
	mid-section	1	2.23	16	1.79±0.45
	old layers	--	--	--	--
45-16	surface layer	--	--	--	--
	mid-section	3	2.65 – 2.94	27	1.75±0.34
	old layers	2	≥4	1	0.11±0.11
45-21	surface layer	3	< 0.2	1	0.05±0.05
	mid-section	15	1.78 – 2.58	129	1.61±0.15
	old layers	--	--	--	--
49-53	surface layer	--	--	--	--
	mid-section	27	1.71 – 3.18	127	1.90±0.17
	old layers	--	--	--	--
All	**surface layer**	**5**	**< 0.2**	**2**	**0.05±0.04**
	mid-section	**45**	**1.71 – 3.18**	**288**	**1.79±0.10**
	old layers	**2**	**≥4**	**1**	**0.11±0.11**
Background – commercial Fe blanks		99	--	7	0.042±0.015

Table2: 60Fe/Fe isotope ratios from AMS measurement on 52 sediment samples from the Indian Ocean
Image: Supplementary information, Wallner, A. et al. Phys. Rev. Lett. 114, 041101 (2015)

Supernovae as the source:

2 events
→ **1.7** million to **3.2** million years ago
→**6.5** million to **8.7** million years ago

Long in duration → not a single blast wave!

Direct: series of supernovae events affecting Solar System

Indirect: Solar System passed by ISM polluted by products of supernovae

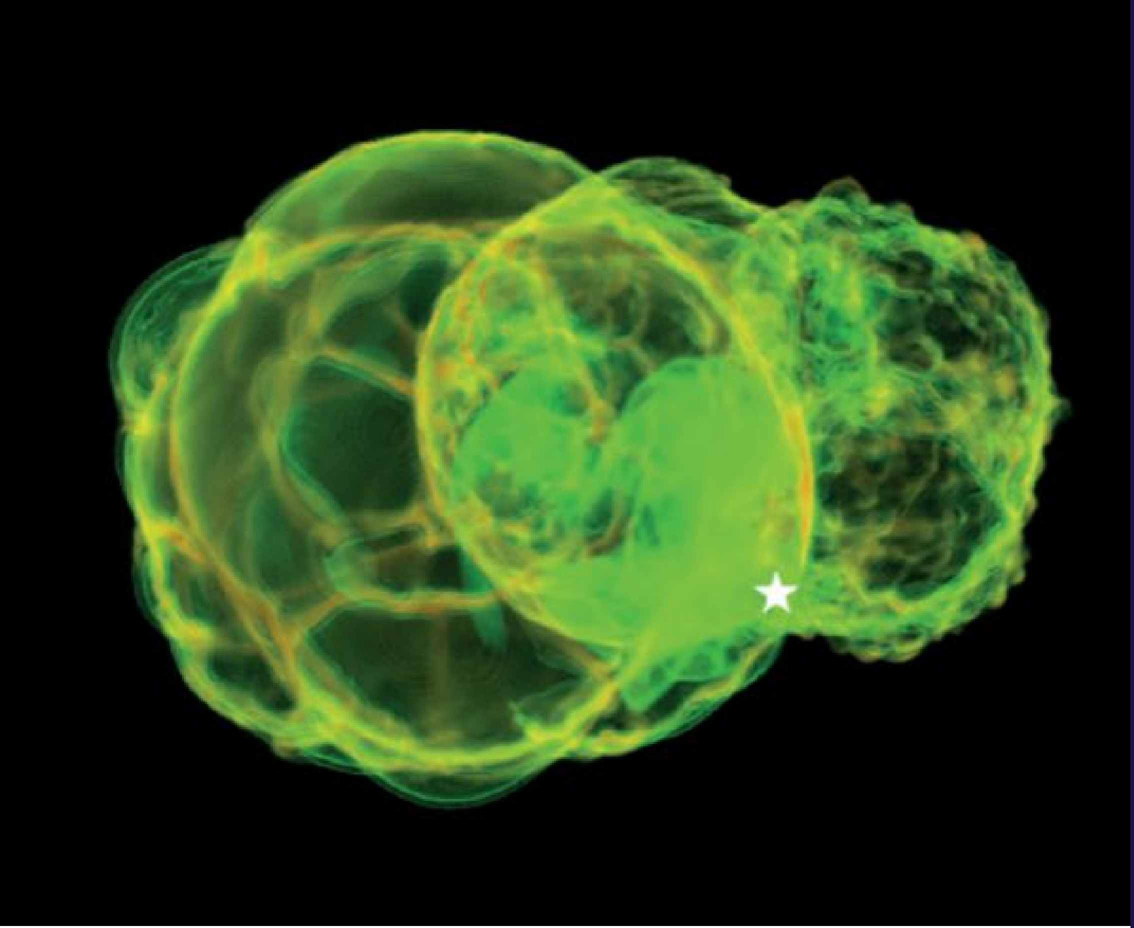

Fig4: Local Bubble (foreground, right) and the Loop I superbubble (left). Central solid green patch near Earth (white star) shows the mass distribution of the ^{60}Fe associated with the two bubbles 2.3 million years ago

Breitschwerdt et al.[3]:

Simulations of trajectory of ^{60}Fe expelled supernovae that formed the Local Bubble and calculations of the explosion's times and sites agree with previous measurements.

What's next?

First event coincides with a strong increase in 3 He and temperature change at about 8 Myr ago, while the second about 3 Myr ago occurred at the same time as Earth's temperature started to drop during the Plio–Pleistocene transition.

Link between supernova activity and changes on Earth?

References

1. Wallner, A. et al. Phys. Rev. Lett. 114, 041101 (2015)
2. Wallner, A. et al. Nature 532, 69–72 (2016)
3. Breitschwerdt, D. et al. Nature 532, 73–76 (2016)