LONG-LIVED RADIONUCLIDES AS INDICATIONS OF A CLOSE-BY SUPERNova EXPLOSION IN DEEP-SEA SEDIMENT CORES

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The Solar Neighborhood

- We live in a large cavity of thin, hot gas
- Extensions: 80-200 pc \( \times \) 600 pc
- The solar system is embedded in a denser, cooler cloud
- Formation of the Local Bubble by supernova explosions starting \( \sim 14 \) Myr ago
- 14-20 SN occurred in a stellar moving group of stars belonging today to subgroups UCL and LCC of Sco-Cen
What happens, if a supernova explodes close to the solar system?

- Nuclides are ejected and entrained in the SN shell
- Expands rapidly through the interstellar medium
- SN envelope will hit the Earth
- Traces are left in terrestrial archives

Courtesy of TU Munich
How can the SN ejecta penetrate to Earth?

- **Scenario 1:**
  SN plasma overwhelms the solar wind $\Rightarrow$ engulfs the Earth in ejecta

- Hydrodynamic simulation of collision of the supernova ejecta with the solar wind
  - Distance of supernova: 10 pc
  - White circle: 1 AU
  - But: distance $\leq$ 10pc $\Rightarrow$ biological damage!!
  - $\Rightarrow$ distance $> 10$ pc

Simulation by T. Athanassiadou et al. 2010
Scenario 2: Delivery as freshly synthesized dust!

Dust grains will decouple from the supernova plasma

Poynting-Robertson effect: dust grains spiral into the sun
An enhanced concentration of $^{60}\text{Fe}$ was measured in the Pacific ferromanganese crust from a depth of 4830 m.

$^{60}\text{Fe}/\text{Fe}$ vs. the age in the crust 237KD.
Mainly Cosmogenic:

- $^{10}\text{Be} \ (t_{1/2}=1.4 \text{ Myr})$:
  - Constantly produced in the Earth’s atmosphere
  - Measurement for dating purposes

Supernova Candidate Isotopes

- $^{26}\text{Al} \ (t_{1/2}=0.72 \text{ Myr})$:
  - Produced in the Earth’s atmosphere, stars, SNe
  - $\sim$ Constant $^{26}\text{Al}$ flux with SN signal on top

- $^{53}\text{Mn} \ (t_{1/2}=3.7 \text{ Myr})$:
  - Produced in cosmic dust, massive stars, SNe

- $^{60}\text{Fe} \ (t_{1/2}=2.6 \text{ Myr})$:
  - Synthesized in massive stars and supernova-isotope
  - NOT produced in-situ on Earth
SN-produced Radionuclides in Deep-Sea Sediments

Two sediment cores from the Indian Ocean

Courtesy of Google Maps (map) and www.navsource.org (ship).
SN-produced Radionuclides in Deep-Sea Sediments

Advantage:
- Sediment accumulation rate is higher than the growth rate of the ferromanganese crust:
  - Crust: 2.37 mm/Myr
  - Sediment cores: 3-4 mm/kyr
  - Factor 1000
  - Resolve the signal
  - Constrain time period of the incoming shock wave

Disadvantage:
- Signal might be diluted
**Dating of the Sediment Cores**

- Pre-dating with Magnetostratigraphy
- Ferromagnetic particles align with magnetic field at time of deposition
- Black regions: normal magnetic field, white: reverse
- **E45-21:**
  - 299 cm $\approx \sim 0.7$ Myr
  - $\sim$ sediment accumulation rate: $\sim 4.3$ mm/kyr
- **E49-53:**
  - 397 cm $\approx \sim 1.4$ Myr
  - $\sim$ sediment accumulation rate: $\sim 2.8$ mm/kyr

Where do we expect to see a signal in our Sediment cores? Magnetostratigraphy by Allison & Ledbetter 1982.
Samples are processed at Helmholtz-Zentrum Dresden-Rossendorf

Procedure takes ~2 weeks (7 samples)

71 samples ~ several months of sample preparation

Starting weight: 3 g

Result: a few mg of Al₂O₃, BeO, Fe₂O₃, MnO₂

Merchel & Herpers 1999: Schematic separation flow chart
Participating AMS Facilities

- University of Vienna, VERA
- ANU Canberra (Toni Wallner)
- HZDR Dresden, DREAMS (Silke Merchel, Georg Rugel)
- TU Munich (Gunther Korschinek)
First AMS measurement results of $^{10}\text{Be}/^{9}\text{Be}$

- $^{10}\text{Be}/^{9}\text{Be}$ vs Age in both cores measured with DREAMS
- Expected initial $^{10}\text{Be}/^{9}\text{Be}$ ratio in the Indian Ocean: $\sim 10^{-7}$
- $^{10}\text{Be}$ variability in sediments due to
  - climate change
  - change of magnetic field
AMS measurements at VERA Laboratory, Vienna

$^{26}\text{Al}/^{27}\text{Al}$ vs Age in both cores

Data points tend towards the exponential decay curve and agree with each other

$\sim^{26}\text{Al}$ suitable for dating

AMS measurement of $^{26}\text{Al}/^{27}\text{Al}$ at VERA.
We live in a cavity of thin, hot medium produced by supernova explosions

An $^{60}$Fe signal was found in a ferromanganese crust

Continue the search in deep-sea sediment cores from the Indian Ocean

Detect signals of the radionuclides $^{26}$Al, $^{60}$Fe, $^{53}$Mn

Confirm and resolve the peak, relative dating with $^{10}$Be/$^{9}$Be measurements

First results show good agreement with exponential decay curve

$^{26}$Al might be suitable for dating purposes