# Long-Lived Radionuclides as Indications of a Close-by Supernova Explosion in Deep-Sea Sediment Cores

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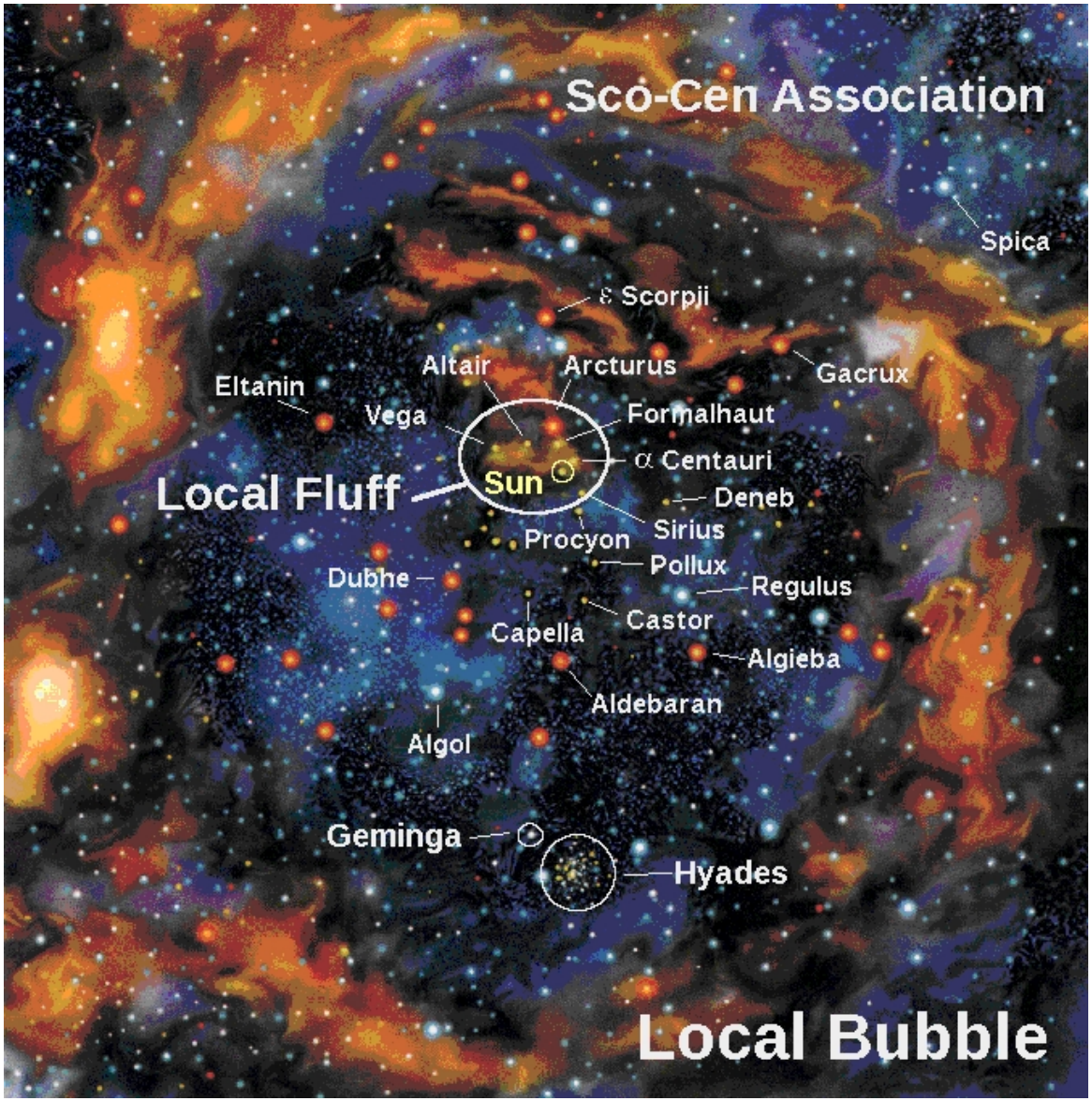
14. June 2013

# The Solar Neighborhood

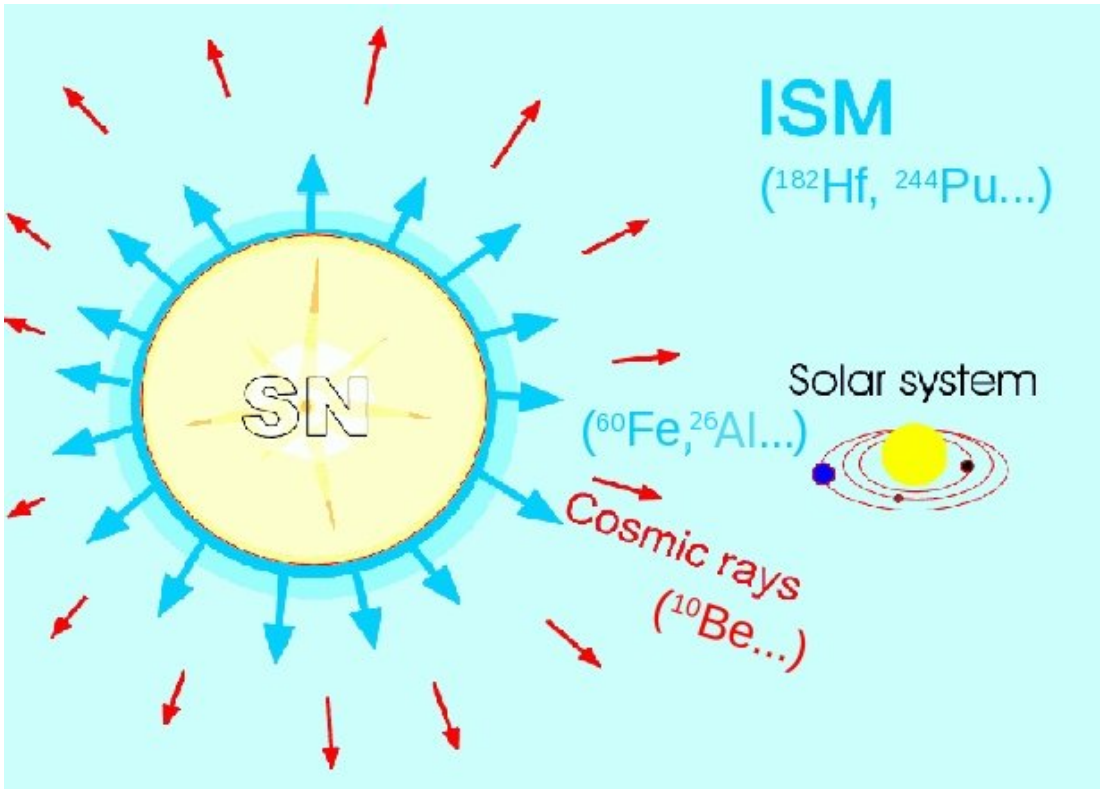



- We live in a large cavity of thin, hot gas
- Extensions: 80-200 $pc^2 \times 600$ pc
- The solar system is embedded in a denser, cooler cloud
- Formation of the Local Bubble by supernova explosions starting $\sim$14 Myr ago
- 14-20 SN occured in a stellar moving group of stars belonging today to subgroups UCL and LCC of Sco-Cen

# Supernova Explosion in the Solar Vicinity

**What happens, if a supernova explodes close to the solar system?**

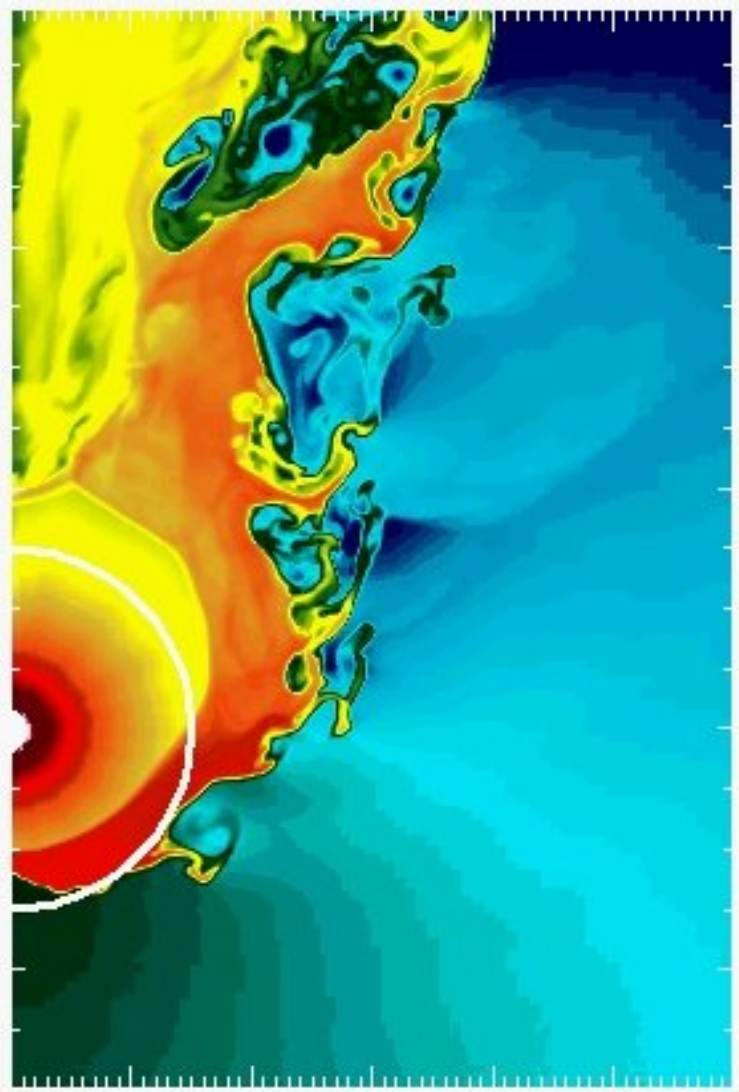
- Nuclides are ejected and entrained in the SN shell
- Expands rapidly through the interstellar medium
- SN envelope will hit the Earth
- Traces are left in terrestrial archives




Courtesy of TU Munich

**How can the SN ejecta penetrate to Earth?**

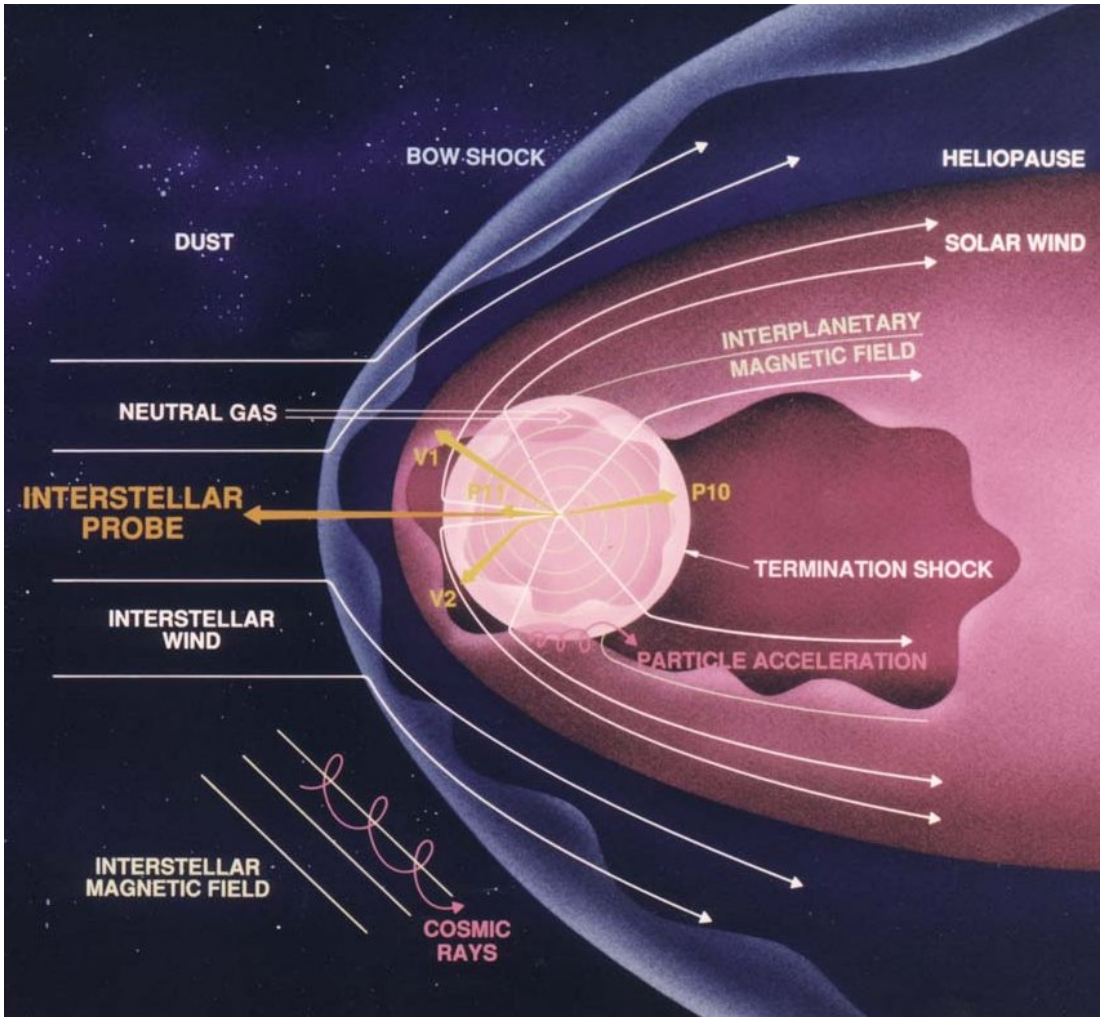
- **Scenario 1**:
  SN plasma overwhelms the solar wind $\rightsquigarrow$ engulfs the Earth in ejecta
- Hydrodynamic simulation of collision of the supernova ejecta with the solar wind
  - Distance of supernova: 10 pc
  - White circle: 1 AU
  - But: distance $\leq$ 10pc
    $\rightsquigarrow$ biological damage!!
  - $\rightsquigarrow$ distance $>$ 10 pc



Simulation by T. Athanassiadou et al. 2010

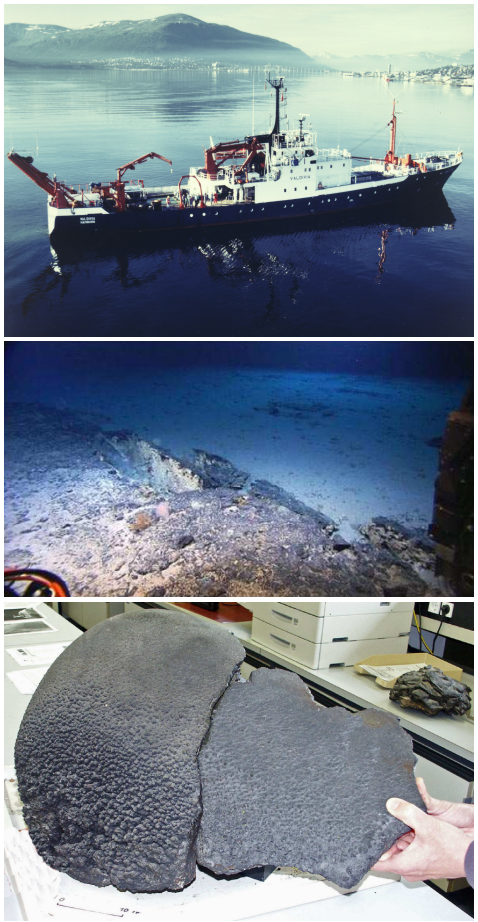
# Transport to the Solar System

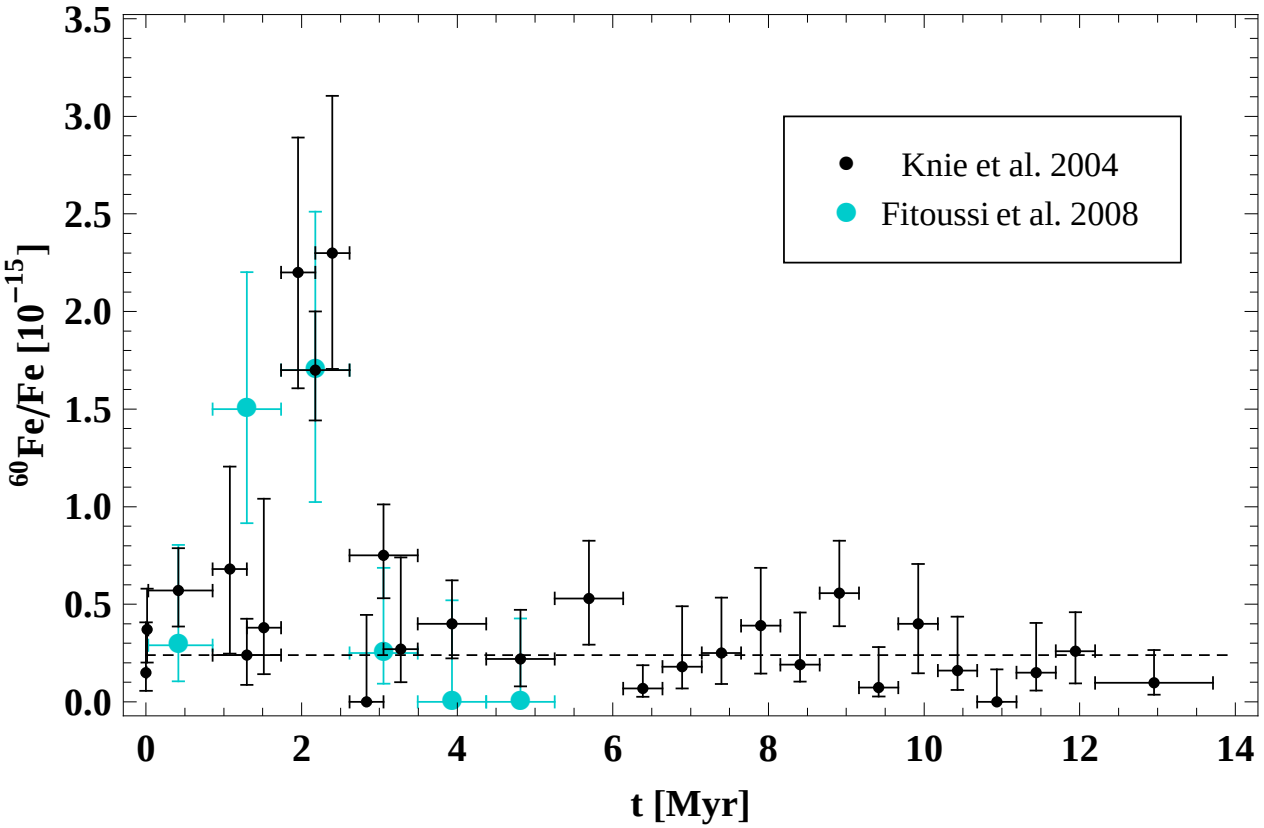
- **Scenario 2**: Delivery as freshly synthesized dust!
- Dust grains will decouple from the supernova plasma
- Poynting-Robertson effect: dust grains spiral into the sun



# SN-produced Radionuclides on Earth

An enhanced concentration of $^{60}$Fe was measured in the pacific ferromanganese crust from a depth of 4830 m.



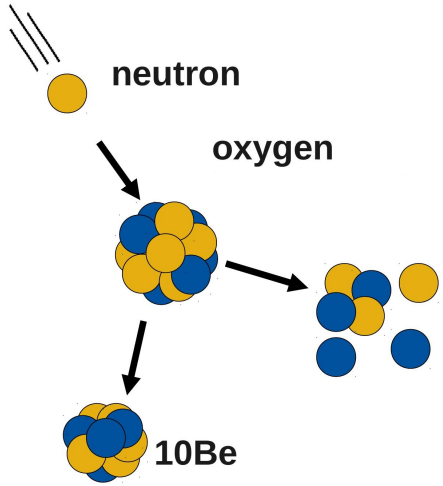



$^{60}$Fe/Fe vs. the age in the crust 237KD.

# Target Isotopes

## Mainly Cosmogenic:

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




Courtesy of Silke Merchel

## Supernova Candidate Isotopes

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

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

- **$^{60}$Fe** ($t_{1/2}$=2.6 Myr):
  - Synthesized in massive stars and supernova-isotope
  - **NOT** produced in-situ on Earth

## Two sediment cores from the Indian Ocean






Courtesy of Google Maps (map) and www.navsource.org (ship).

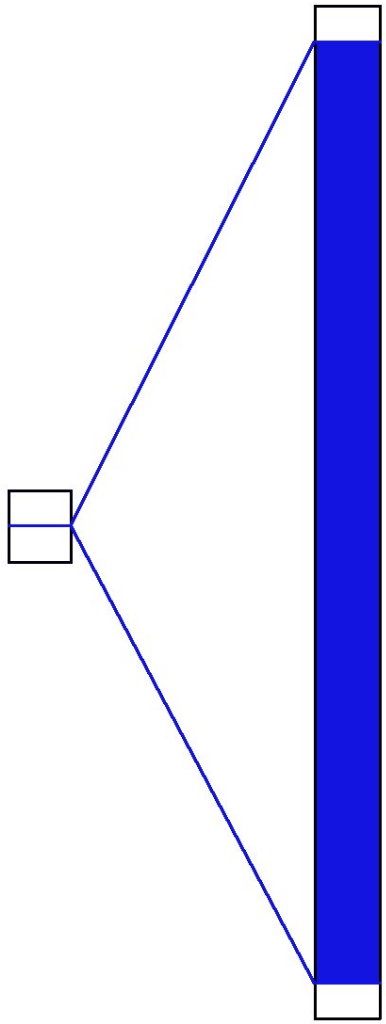
# SN-produced Radionuclides in Deep-Sea Sediments

**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
  - $\rightsquigarrow$ Resolve the signal
  - $\rightsquigarrow$ Constrain time period of the incoming shock wave

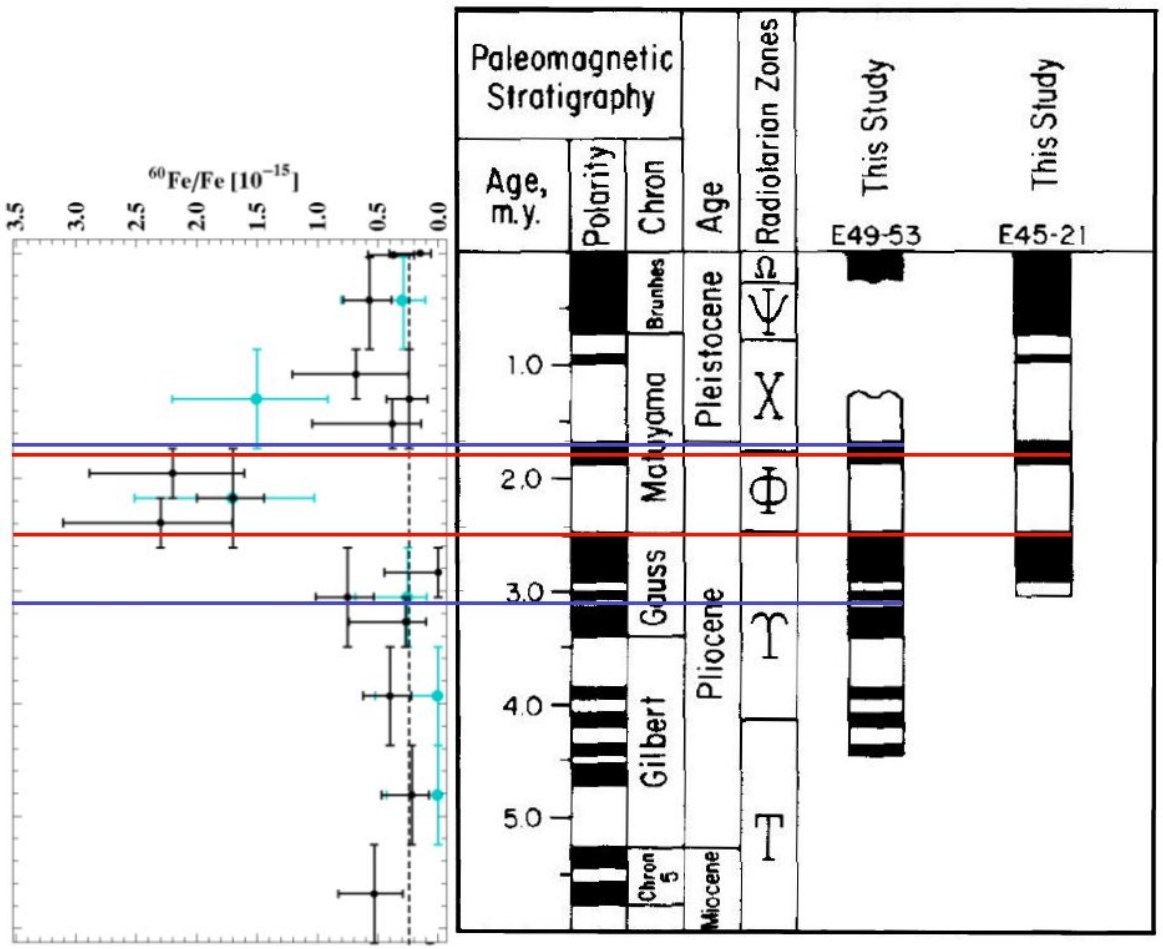
**Disadvantage:**

- Signal might be diluted



# Dating of the Sediment Cores

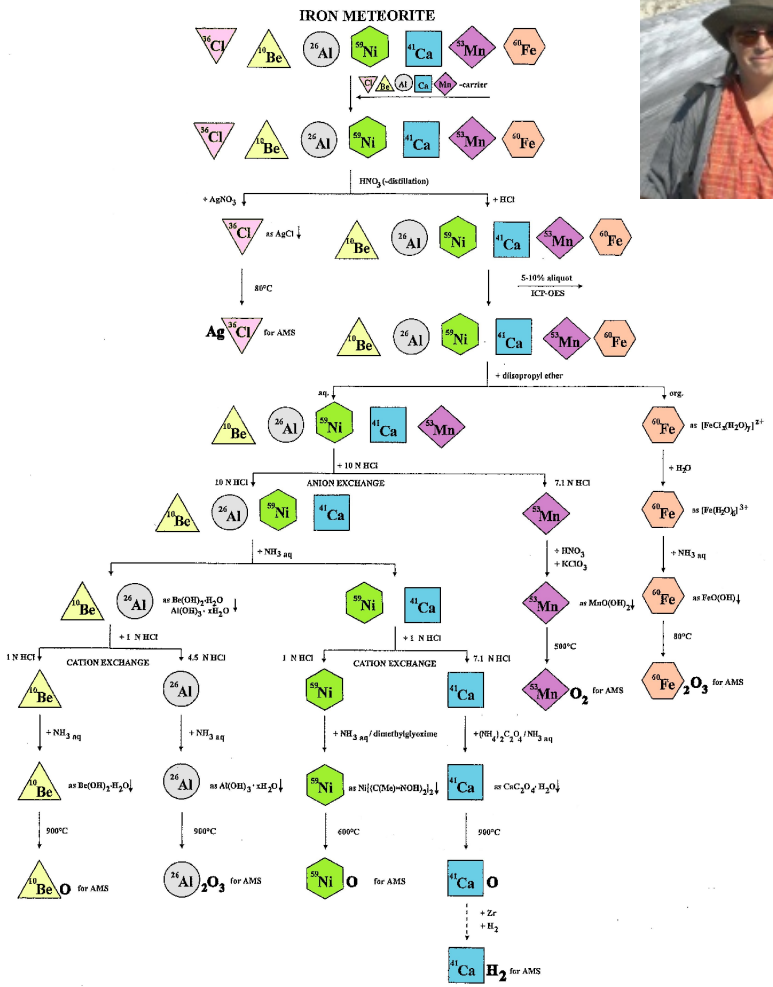
- Pre-dating with Magnetostratigraphy
- Ferromagnetic particles align with magnetic field at time of deposition
- Black regions: normal magnetic field, white: reverse
- **E45-21:**
  299 cm $\hat{=}$ ~0.7 Myr
  $\rightsquigarrow$ sediment accumulation rate: ~4.3 mm/kyr
- **E49-53:**
  397 cm $\hat{=}$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




Where do we expect to see a signal in in our Sediment cores? Magnetostratigraphy by Allison & Ledbetter 1982.

# Chemical Sample Preparation

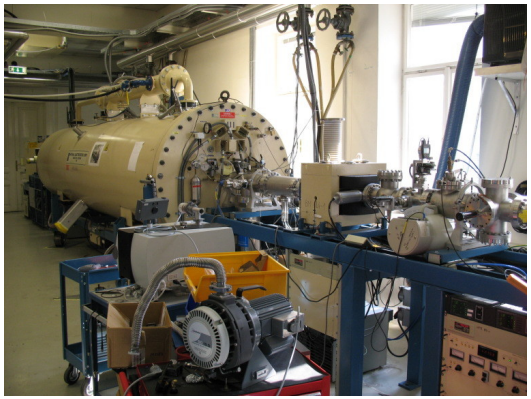
- Samples are processed at Helmholtz-Zentrum Dresden-Rossendorf
- Procedure takes ~2 weeks (7 samples)
- 71 samples $\rightsquigarrow$ several months of sample preparation
- Starting weight: 3 g
- Result: a few mg of $Al_2O_3$, BeO, $Fe_2O_3$, $MnO_2$




Merchel & Herpers 1999: Schematic separation flow chart

# AMS Measurements

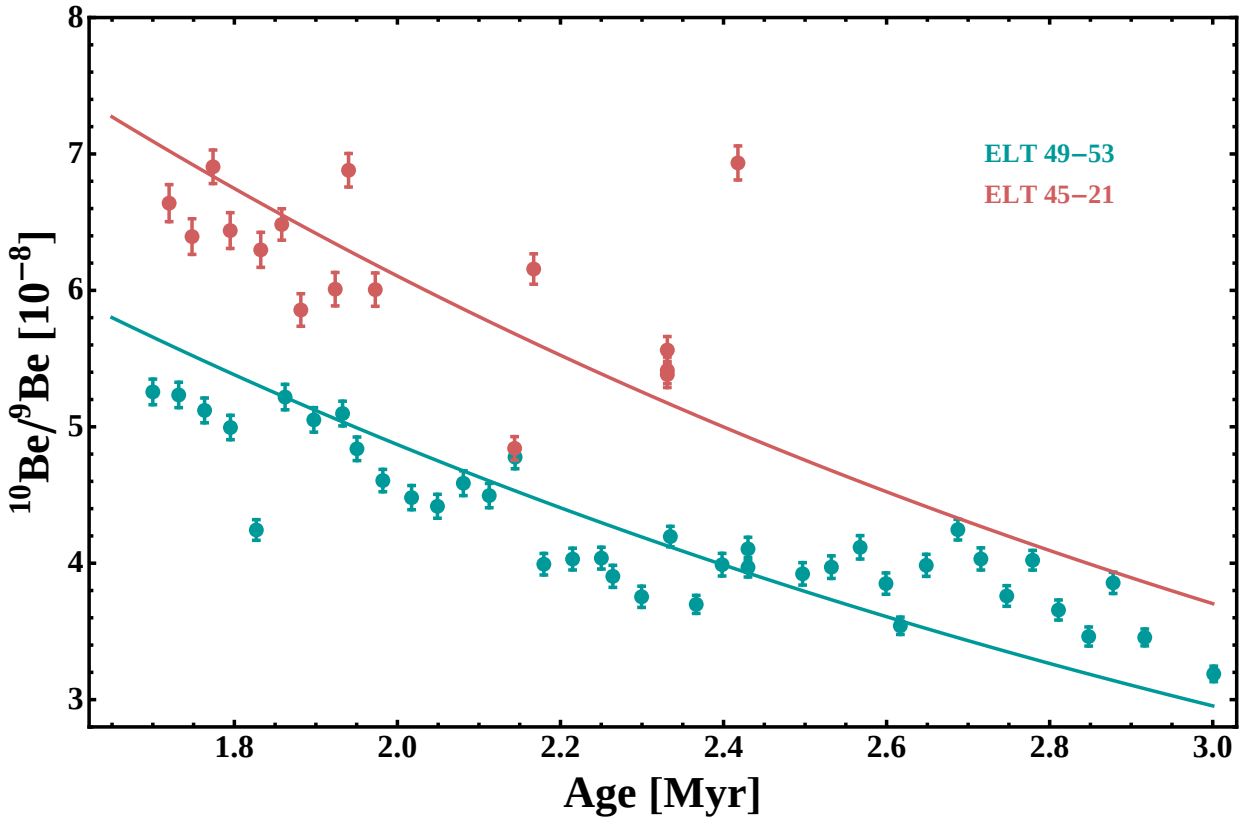




- Participating **AMS Facilities**
  - University of Vienna, VERA
  - ANU Canberra (Toni Wallner)
  - HZDR Dresden, DREAMS (Silke Merchel, Georg Rugel)
  - TU Munich (Gunther Korschinek)

# First Measurement Results of $^{10}Be/^{9}Be$

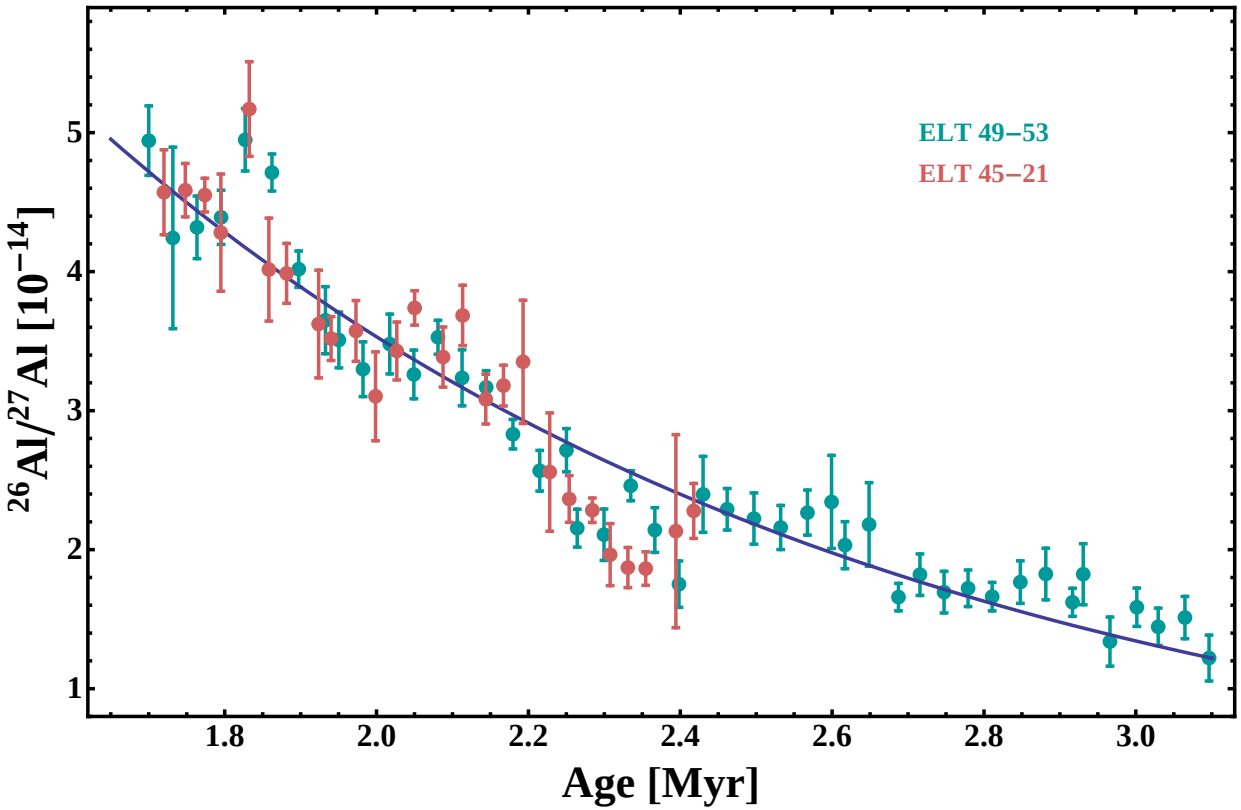
- $^{10}Be/^{9}Be$ vs Age in both cores measured with DREAMS
- Expected initial $^{10}Be/^{9}Be$ ratio in the Indian Ocean: $\sim 10^{-7}$
- $^{10}Be$ variability in sediments due to
  - climate change
  - change of magnetic field




First AMS measurement of $^{10}Be/^{9}Be$ at DREAMS.

# First Measurement Results of $^{26}Al/^{27}Al$

- AMS measurements at VERA Laboratory, Vienna
- $^{26}Al/^{27}Al$ vs Age in both cores
- Data points tend towards the exponential decay curve and agree with each other
- $\rightsquigarrow$ $^{26}Al$ suitable for dating




AMS measurement of $^{26}Al/^{27}Al$ at VERA.

# Conclusions

- 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