Solar particles

Grimberg et al. (2006) Science 314 1133
Implantation depth according to SRIM (nm)

Grimberg et al. (2006) Science 314 1133
Ne implantation comparison

Grimberg et al. (2006) Science 314 1133
Solar (SCR) and galactic (GCR) cosmic-rays

Trajectory of a cosmic ray
Cosmic rays and rotation of the galaxy
Energies carried by GCR (typically 100 MeV to 10 GeV) are thought to derive from supernovae (SN) explosions. There is a considerable amount of evidence that this acceleration is accomplished in the shock waves of SN explosions as they travel through the surrounding interstellar gas. Whenever the Sun was located in a region of the galactic spiral arms which show star formation regions (OB associations), an increased GCR flux has to be expected.
Sun’s orbit
Local structures

- Betelgeuse
- Antares
- The Sun
- Beta Canis Majoris

The Local Bubble

*artist rendering*
OB associations

The Southern Cross
Cosmic ray abundances

[Graph showing relative abundances of various elements in cosmic rays compared to the solar system.]
Galactic cosmic ray neon
Superbubble Origin of Galactic Cosmic Rays Supported by Supernova-Produced Isotopes
Support for origin of GCR in O-B association
The Villalbeto de la Peña meteorite fall
Iron meteorite on Mars?
**Length of exposure to GCR: CRE ages of meteorites**

**Chronometer: $^{81}$Kr-$^{83}$Kr**

$T_{1/2}^{(81}Kr)=0.228\text{Ma}$

$\quad^{81}Kr(t) = \left( \frac{P_{81}}{\lambda_{81}} \right) \left( 1 - \exp(-\lambda_{81} \ t) \right)$

$\quad F(T_{\text{CRE}}) = \left[ ^{83}Kr_c \right] / \left[ ^{81}Kr \right]$

$\quad = \left( \frac{P_{83}}{P_{81}} \right) \lambda_{81} \ T_{\text{CRE}} / [(1 - \exp (-\lambda_{81} \ T_{\text{CRE}}))]^{-1} - 1$

**Chronometer: $^{36}$Cl-$^{36}$Ar**

$T_{1/2}(^{36}Cl)=0.30\text{Ma}, \quad P(^{36}Cl)/P(^{36}Ar)=0.83$

$\quad^{36}Cl(t) = \left( \frac{P (^{36}Cl)}{\lambda_{36}} \right) \left( 1 - \exp(-\lambda_{36} \ t) \right)$

$\quad F(T_{\text{CRE}}) = \left[ ^{36}Ar \right] / \left[ ^{36}Cl \right]$

$\quad = P_{36}(^{36}Ar)/P_{36}(^{36}Cl) \lambda_{36} \ T_{\text{CRE}} / [1 - \exp (-\lambda_{36} \ T_{\text{CRE}})]^{-1} - 1$
Length of exposure to GCR: CRE ages of meteorites

**Chronometer: $^{53}$Mn-$^{53}$Cr**

$T_{1/2}(^{53}\text{Mn})=3.7\text{Ma}$

$^{53}\text{Mn}(t) = \left(\frac{P(^{53}\text{Mn})}{\lambda_{53}}\right) \left(1 - \exp\left(-\lambda_{53} t\right)\right)$

$F(T_{\text{CRE}}) = \left[\frac{^{53}\text{Cr}}{^{53}\text{Mn}}\right]$

$= \lambda_{53} T_{\text{CRE}} \left[\frac{P(^{53}\text{Cr}_c)}{P(^{53}\text{Mn})}\right] \left[1 - \exp\left(-\lambda_{53} T_{\text{CRE}}\right)\right]^{-1}$

**Chronometer: $^{129}$I-$^{129}$Xe**

$T_{1/2}(^{129}\text{I})=15.7\text{Ma}$

The $^{129}$I concentration is given by:

$^{129}\text{I}(t) = \frac{P_{129}}{\lambda_{129}} \left[1 - \exp\left(-\lambda_{129} t\right)\right]$,

$F(T_{\text{CRE}}) = \left[\frac{^{129}\text{Xe}_c}{^{129}\text{I}}\right]$

$= \lambda_{129} T_{\text{CRE}} \left[1 - \exp\left(-\lambda_{129} T_{\text{CRE}}\right)\right]^{-1}$
# I-Xe chronology

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<th>128</th>
<th>129</th>
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Xe in Cape York troilite

Cape York troilite Xe is normalized to OC-Xe
Neutron capture in Te

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2007. 2. 28.
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Neutron excesses in Troilite D4

Shifts due to thermal and epi-thermal neutron capture
Troilite D4, Cape York

![Graph showing isotope data for Troilite D4, Cape York. The x-axis represents $^{129}$Xe$_{excess}$ ($10^{-14}$ cm$^2$STP/g) and the y-axis represents $^{128}$Xe$_{excess}$ ($10^{-14}$ cm$^2$STP/g). The graph includes data points and error bars.](image-url)
Xe produced in Te of Cape York troilite
### $^{129}\text{I} - ^{129}\text{Xe}$ CRE age of Cape York

<table>
<thead>
<tr>
<th>Troilite</th>
<th>$^{129}\text{Xe}_c$ (10$^6$ at/g)</th>
<th>$^{129}\text{I}$ (10$^6$ at/g)</th>
<th>$^{129}\text{Xe}_c/^{129}\text{I}$</th>
<th>CRE age (Ma)</th>
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<tr>
<td>D4</td>
<td>26.5 ± 1.5</td>
<td>9.74 ± 0.55</td>
<td>2.72 ± 0.55</td>
<td>82 ± 7</td>
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<tr>
<td>U1</td>
<td>26.8 ± 3.2</td>
<td>8.34 ± 1.33</td>
<td>3.21 ± 1.33</td>
<td>94 ± 20</td>
</tr>
</tbody>
</table>

(Murty and Marti, 1987)

$[\lambda_{129} = 4.41 \times 10^{-8} \text{ a}^{-1}]$
Graphic by Nancy Hulbirt for PSRD based on a concept by Paul Spudis, APL.
Conclusions

- The intensity of cosmic rays in the inner solar system is observed to vary with time over a variety of time scales. The Sun is the cause of some of these variations, but the observed longer-term variations reflect changes in the local interstellar medium.

- Galactic cosmic rays (GCR) dominate the average intensity of energetic particles above about 200 MeV and are affected by supernova shock waves.
Conclusions

- The cosmic-ray intensity has been studied using satellites for short-term variations and terrestrial and extraterrestrial materials for the longer-term variations, for the last 1 Ma.

- Iron meteorites and lunar rocks are suitable GCR monitors for the last 1 Ga time period. The $^{41}$K/$^{40}$K chronometer (1.26 Ga) shows that the flux was smaller than today. $^{81}$Kr/$^{83}$Kr, $^{53}$Mn/$^{53}$Cr and $^{129}$I/$^{129}$Xe are studied by the Solar Neighborhood Consortium for flux changes during the past 50 Ma.
Monte Carlo simulation of GCR neutron flux

\[ J_0(E > 10 \text{ MeV}) = 1 \text{ proton cm}^{-2} \text{ s}^{-1} \]
Thank you
STEREO Joins ACE to Witness the Last (?) Large SEP events of Cycle 23
The Milky Way in Cygnus. Red areas are emission nebulae, where hydrogen is excited by ultraviolet light from hot stars. The one near Deneb, the brightest star, is called the North America Nebula for its shape. A faint curlicue in the lower part is a supernova remnant known as the Veil Nebula.