

History of Solar and Galactic Cosmic Radiation

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Abstract

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. They are modulated by the Sun and have their lowest intensity during high solar activity. The cosmic-ray intensity has been studied using satellites for short-term variations and terrestrial and extraterrestrial materials for the longer-term variations. Studies of meteorites indicate that the average galactic flux in the inner solar system was only constant for the past few Ma. Iron meteorites are used as GCR monitors for the last 1 Ga time period. The nuclide pair ^{41}K and ^{40}K (1.26 Ga) shows that the flux was smaller in the distant past. The pairs ^{81}Kr - ^{83}Kr , ^{53}Mn - ^{53}Cr and ^{129}I - ^{129}Xe are currently studied by the Solar Neighborhood Consortium for possible resolution of flux changes during the past 50 Ma. Significant improvements in the resolution of flux changes and for the study of the evolution of the solar environment, as a result of the galactic rotation, can be expected from the application of these techniques to suitable lunar GCR monitors.

Origin of CR Flux Changes

The huge energies carried by GCR (typically 100 MeV to 10 GeV) are thought to derive from supernovae (SN) explosions, which occur once every 30 to 60a in the galaxy. In order to maintain the currently observed intensity of GCR over millions of years, only a few percent of the SN energy has to be used for the GCR acceleration. 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.

The GCR flux and the path lengths of GCR reaching the solar system are also affected by the interstellar medium (ISM). The bow shock of the heliosphere can be pushed inward further than 1 AU. As a consequence, the GCR slowing down effect by the heliosphere will cease to work and the flux of lower energy particles will be significantly increased and the solar wind can not reach the Earth-Moon system. The position of the solar system with regard to the star formation regions (the original OB associations have lost their O-members, because these have already ended their cycles as SN), has been investigated in several studies. Some methods are local in the sense that they look at local age gradients in star-forming regions, surviving young objects such as the B stars, or in open clusters. Also a ^{60}Fe anomaly in a deep-sea manganese crust may serve as evidence for a supernova 2.8 Ma ago (Knie et al., 2004).

A comprehensive census of the stellar content of the OB associations within 1 kpc from the Sun was presented by De Zeeuw et al. (1999). This presents a part of a project to study the formation, structure, and evolution of nearby young stellar groups and related star-forming regions. Their OB associations are unbound moving groups which can be detected kinematically because of their small internal velocity dispersion. In general, the intrinsic flux of cosmic rays reaching the outskirts of the solar system is proportional to the star formation rate in the solar system's vicinity. Although there is a lag of several million years between the birth and death of the massive stars which is ultimately responsible for cosmic ray acceleration, this lag may be small when compared with the relevant time scale of GCR flux variations. Model calculations include the galactic star-forming regions and the OB stars lost subsequently as SN, which allows the separation of effects due to spatial and temporal clusterings in the solar neighborhood. Preliminary data suggest major local flux variations on time scales of several Ma to tens of Ma after the penetration of the solar system into the Gould Belt super-bubble, consistent with an inferred recent GCR flux increase of 28%, based on iron meteorite data.

Direct measurements of GCR flux changes and production rate calibrations can be based on a systematic study of cosmic-ray-produced nuclides in selected lunar monitors, (e.g. ilmenites). Radionuclides of 0.2 to 16 Ma

half-lives, as well as associated stable nuclides, which integrate over the time of GCR exposure will permit cross-calibrations over different time-scales.

Considerable progress has also been made in the study of solar (SCR) fluxes using cosmic-ray-produced nuclides in lunar samples. These data show that SCR-produced radionuclides in lunar samples due to fluxes of solar protons above 10 to 100 MeV over the last few Ma are not very different from the contemporary fluxes, and are based on the similarity of the activity-vs.-depth profiles of 2.6 a ^{22}Na and 0.71 Ma ^{26}Al , made by similar proton-induced reactions. However, more precise measurements of SCR-produced nuclides are required from depth-profiles of well-documented lunar rocks, and in separates thereof, to improve SCR flux measurements of long-lived radionuclides ^{26}Al , ^{10}Be and ^{53}Mn .

GCR Flux Monitors

The reevaluation (Lavielle et al., 1999) of the constancy of the GCR flux over the last 0.5 Ga (specifically the interval 150 to 700 Ma ago) was based on ^{40}K - ^{41}K data in the literature. It shows that the average production rate of ^{36}Cl was ~28% lower than the present production rate. Therefore, the present GCR flux apparently is higher than that in the past, but the data do not provide information about the time of increase, nor the possibility of a cyclic variation. Therefore, NASA supports a consortium study of suitable monitors of GCR flux changes in the solar system.

Two chronometers are useful for the determination of the recent GCR flux: ^{81}Kr - $^{83}\text{Kr}_c$ ($t_{1/2} = 0.22$ Ma) and ^{36}Cl - ^{36}Ar ($t_{1/2} = 0.30$ Ma). Both systems self-correct for GCR-shielding variations for a single exposure geometry and are expected to give identical CRE ages. These can be used for cross-calibrations, and to assess a constant geometry. Suitable flux monitors for the past 10 Ma are the pairs ^{53}Cr - ^{53}Mn ($t_{1/2} = 3.7$ Ma) and also ^{21}Ne - ^{10}Be ($t_{1/2} = 1.6$ Ma), which are largely self-correcting for shielding variations in documented lunar monitors. A potential monitor for the 50 Ma time-scale is found in the pair $^{129}\text{Xe}_c$ - ^{129}I ($t_{1/2} = 16$ Ma) in tellurium-containing troilite. The nuclides ^{129}I and $^{129}\text{Xe}_c$ (the decay product) are produced from Te and present a self-correcting system for variable shielding, but the $^{129}\text{Xe}_c$ component needs to be separated from radiogenic ^{129}Xe due to "extinct" ^{129}I . This was shown to be feasible in iron meteorites because of differential temperature releases and the availability of the monitor nuclide ^{131}Xe (Mathew and Marti).

References:

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