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DONALD V. REAMES

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Donald V. Reames

NASA/Goddard Space Flight Center, Greenbelt, Maryland

Abstract:

A new measurement is suggested for obtaining information on the mean age of the galactic cosmic rays. The technique is based on $\sim 2 \times 10^6$ year half-life of Mn^{53} which may be produced copiously below 200 MeV/nucleon by the fragmentation of cosmic-ray Fe^{56} during its passage through interstellar hydrogen.

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NASA/Goddard Space Flight Center, Greenbelt, Maryland

At present, our primary information on the mean age of the galactic cosmic radiation comes from the abundance of the light nuclei, Li, Be and B which are believed to have been produced by fragmentation of heavier nuclei during their passage through interstellar space.[1,2] These abundances imply that the radiation has traversed ~ 4 gm/cm^2 of interstellar material, but owing to variations in the density of that material, the mean age of the cosmic rays inferred can range from 10^6 to 10^9 years for confinement of the radiation to the galactic disk or halo, respectively.

Attempts have also been made to infer the age of the radiation from the shape of the cosmic-ray electron spectrum.[3,4]

A more direct age determination could come from the observation of a long-lived radioactive nuclide in the cosmic rays and Be^{10} has been suggested[5] as a possible candidate. Unfortunately, however, recent measurements[6,7] of the cross-section for production of Be^{10} emphasize the difficulty of detecting this nuclide in the presence of the lighter Be isotopes.[8,9]

With improvements of experimental techniques it has become possible to examine the abundances of elements up to the vicinity of Fe and it has been found that elements immediately below Fe are remarkably consistent with their having been produced by fragmentation of Fe itself during its passage through about 2 gm/cm^2 of interstellar hydrogen.[10,11,12]

This circumstance leads us to suggest the possibility of using the abundance of Mn with its strong dependence of the production of the 2×10^6 year nuclide Mn^{53} as an indicator of the age of cosmic-ray Fe.

Any discussion of a nuclide such as Mn^{53} whose only mode of decay is by orbital electron capture must be prefaced by a discussion of the cross-section for capture of free electrons into orbit at high velocity. Certainly a highly relativistic nucleus would be stripped of orbital electrons and thus prevented from decaying by this mode.

Estimates of the cross-section for the radiative capture of electrons into orbit may be made from the well-understood inverse process, the relativistic photo-electric effect.[13] Using these data and the principle of detailed balance one finds a cross-section which falls below 1 barn at 230 MeV/nucleon and reaches 200 mb at 500 MeV/nucleon. In this region the cross section therefore becomes small with respect to the cross-section for nuclear interaction. The cross-section for non-radiative capture of electrons into orbit may be estimated from the Brinkman-Kramers[14] relation and is found to be almost two orders of magnitude smaller than the radiative capture cross section in this region. Photo-ionization of captured electrons depends on the flux of photons in the 10-100 KeV region and is estimated to be negligibly small, once the cosmic-rays leave the source region.

Therefore, above a few hundred MeV/nucleon any Mn^{53} produced by Fe fragmentation remains stable since it is stripped of orbital electrons.

Below ~ 200 MeV, however, the survival of Mn^{53} depends upon its mean age, τ, relative to its ~ 3×10^6 year mean life.

Cross sections for the production of Mn^{53} have to be calculated by the Monte-Carlo cascade-evaporation of Bertini[15] and also have been estimated using the semi-emperical relation of Rudstam.[16,17] No direct measurements of the cross section for Mn^{53} production exist; such measurements in the 50-200 MeV region of interest are clearly needed.

The predicted ratio of the fluxes of Cr and Mn are shown in Fig. 1 for the cases of Mn^{53} survival and decay using each of the theoretical predictions of the cross section. Also plotted are measurements[12,18,19,20] of this ratio for the galactic cosmic rays. If the intranuclear-cascade cross sections are correct, a young age associated with local origin and/or containment in the galactic disk seems to be most consistent with the available data; such a conclusion, however, must be regarded as highly tentative at present.

Finally it should be noted that the results would be sensitive to the presence of Mn or Cr in the source. The abundance[21,22] of these elements in the source are probably $\lesssim$ 10% of Fe. It should be possible to eliminate contributions from the source by observing the Cr to Mn ratio at high energies and by observing its energy dependence. The Cr to Mn ratio should be highly insensitive to propagation-model dependent effects such as distributions in interstellar path length insofar as their energy dependence is small in the 50-200 MeV/nucleon region.

While low energy measurements of the iron fragmentation cross sections are clearly required (especially Fe^{56} (p, α) Mn^{53}), an estimate of the mean age of the cosmic radiation based on Mn^{53} presently appears more readily accessible than one based on Be^{10} whose production cross section is known to be lower than that of its neighbors by an order of magnitude.

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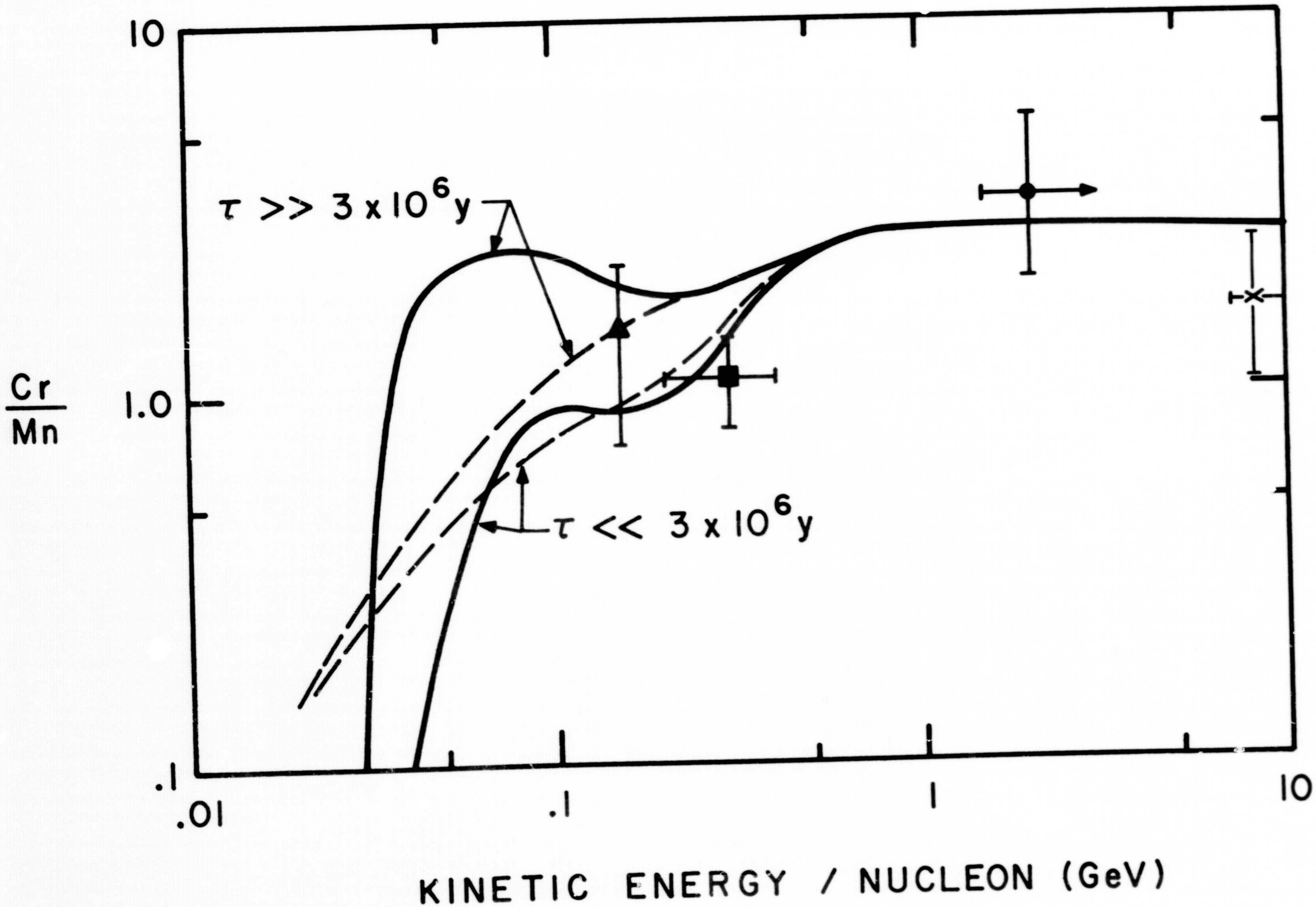
FIGURE CAPTION

Fig. 1. The ratio of Cr to Mn in the cosmic radiation. Curves are the theoretically predicted ratio for the cases of Mn^{53} survival ($\tau \ll 3 \times 10^6$ y) and decay ($\tau \gg 3 \times 10^6$ y) using the intranuclear-cascade calculations of Bertini (solid curves) and the semi-emperical Rudstam relation (dashed curves). Data shown by the triangle, square, circle and cross are taken from Refs. 12, 18, 11 (see Ref. 19) and 20 respectively.



Cr/Mn
10
1.0
.1
.01
.1
1
10
τ >> 3 x 10^6 y
τ << 3 x 10^6 y
KINETIC ENERGY / NUCLEON (GeV)