THE ISOTOPIC COMPOSITION OF ANOMALOUS COSMIC-RAY NEON

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Abstract

We have used observations of neon in the energy interval 14.6 - 35.6 MeV/nuc from the cosmic-ray experiment on the Voyager 2 (V2) spacecraft during 1986-1988 to derive the $^{22}Ne/^{20}Ne$ ratio for the source material of the anomalous cosmic rays (ACRs). Because of the relatively small contamination from galactic cosmic-ray (GCR) neon during the time period selected, we have significantly improved the precision with which this ratio is known. We find that the derived ACR source ratio, $^{22}Ne/^{20}Ne = 0.077^{+0.068}_{-0.043}$, is consistent with the composition of the solar wind (0.073) and meteoritic neon-A (0.12), but inconsistent with the galactic cosmic ray source (0.43). This finding places new limits on the possible source material of the anomalous component. If the anomalous component does derive from the inward flowing interstellar neutral gas, then the composition of the source of galactic cosmic rays differs from that of the very local interstellar medium (VLISM).

Introduction. The anomalous component of cosmic rays is characterized by flux enhancements of the elements He, C, N, O, Ne, Ar, and possibly H below ~50 MeV/nuc during periods of solar minimum conditions (see Cummings and Stone, 1990, for discussion of the elemental composition). They are attributed to interstellar neutral atoms which penetrate into the heliosphere (Fisk et al., 1974), become ionized and swept out to the solar wind termination shock, where they are thought to be accelerated (Pesses et al., 1981; Jokipii, 1986). They are therefore a unique, direct sample of the local interstellar medium and their isotopic composition is of interest. Unlike the ACR elemental composition, the isotopic composition of a given element is expected to be relatively unaffected by acceleration and modulation processes in the heliosphere.

Previous studies of the isotopic composition of anomalous cosmic-ray He, N, O, and Ne have indicated that they are relatively pure ^{4}He, ^{14}N, ^{16}O, and ^{20}Ne (see review by Mewaldt, 1988). The anomalous cosmic rays are therefore not fragmented as are the galactic cosmic rays and thus bear the isotopic signature of their source.

Several different $^{22}Ne/^{20}Ne$ ratios have been reported for solar system and galactic material (Mewaldt, 1988) and a comparison of these observations with the ACR results has bearing on the origin of the different samples. Very few

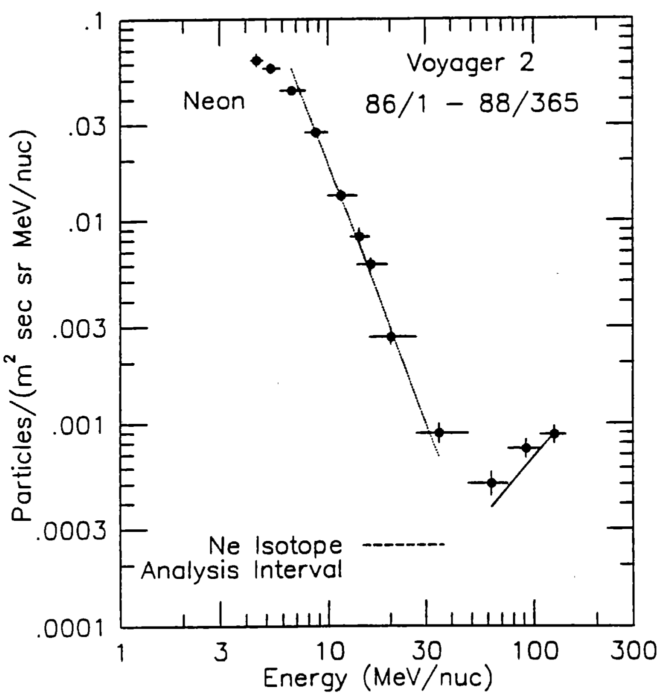

Figure 1. Differential energy spectrum of Ne from V2 during 1986/1- 1988/365.

measurements of the isotopic composition of ACRs exist (see Mewaldt et al., 1984, for data and references). This work is an extension of an analysis carried out by Smith and McDonald (1983) using data from the Voyager cosmic-ray instrument for the period near the previous solar minimum (1977-79) when the ACR fluxes were approximately 5 times lower than during the present analysis. The present measurement offers improved statistics and reduced contamination from galactic cosmic rays and thus allows a more accurate comparison of the isotopic composition of ACR Ne with the other samples of solar and galactic Ne.

Observations. The differential energy spectrum of Ne for the time period 1986-88 obtained from V2 is shown in Figure 1. The large increase in intensity below ~30 MeV/nuc is due to ACR neon. The dotted line is a least-squares fit to a power-law for the 10-20 MeV/nuc energy range. The solid line is a fit to the estimated GCR neon spectrum, which was determined after first correcting the observed neon intensities in the 60-120 MeV/nuc energy range for contamination from ACR neon.

The isotope analysis utilizes the HET 1 "A" end telescope in its high-gain mode (see Stone et al., 1977, for a description of the instrument). There are two thin front detectors, A1 and A2, each of thickness ~150 μm, followed by a stack of seven 3 mm detectors. In this analysis we use only those particles which penetrate A2 and come to rest in the "stack". We use the dE/dX $\times$ E$'$ technique (analogous to that used by Breneman, 1985, for nuclear charge Z), to derive two measures of the mass of the incident nucleus, M1 from $\Delta E_{A1} \times (E_{A2} + E_{stack})$ and M2 from $\Delta E_{A2} \times E_{stack}$.

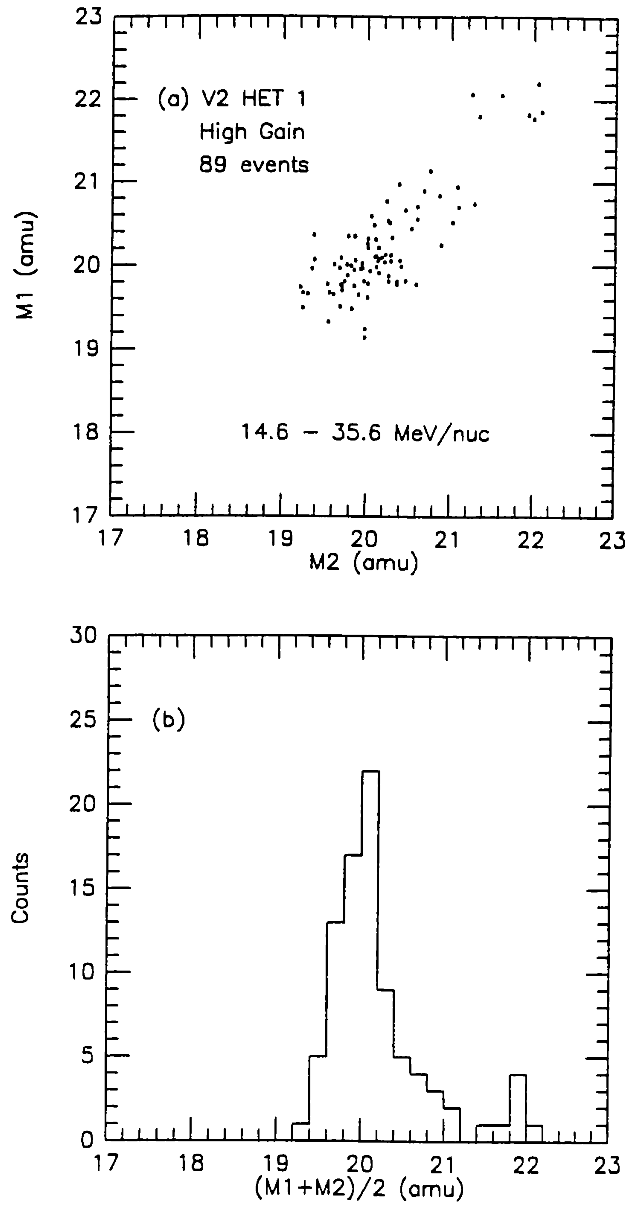

Figure 2. (a) M1 vs. M2 (see text). Mass consistency requirements, $|M1 - M2| < 1$, were imposed on the data before plotting. (b) Histogram of (M1+M2)/2 for the data in (a).

The horizontal dashed bar in Figure 1 shows the Ne energy interval selected for the isotope study. Data at energies below this interval were not used because they are derived from telescopes and gain states with somewhat poorer mass resolution. The energy intervals for ^{20}Ne and ^{22}Ne were selected to be the same and hence no spectral correction to the observed ratio was necessary. However, in deriving the ACR ^{22}Ne/^{20}Ne source ratio we did make corrections for an expected spectral energy shift

TABLE 1. Isotopic Composition of Anomalous Cosmic-Ray Neon Source.

Isotope	Obs N	Obs ratio	Calc GCR N	ACR N	ACR ratio	"Shift" factor	"Accel" factor	ACR-source ratio
^{20}Ne	82	0.085	2.6	79.4	0.066	1.38	0.84	$0.077^{+0.068}_{-0.043}$ (a)
^{22}Ne	7		1.7	5.3				
^{20}Ne	24	0.17	5.5	18.5	0.017	1.28	0.84	$0.018^{+0.26}_{-0.16}$ (b)
^{22}Ne	4		3.7	0.3				

[a] This work: 14.6 - 35.6 MeV/nuc.
[b] Smith and McDonald: 15.5 - 35 MeV/nuc.

and for differences in acceleration and propagation. These corrections are described below.

The observed M1 versus M2 correlation plot for the 14.6 - 35.6 MeV/nuc energy bin is shown in Figure 2a. The small ^{22}Ne distribution (7 events) is clearly well-separated from the larger distribution of ^{20}Ne (82 events). Figure 2b shows the resulting histogram of the average mass in amu. The mass resolution achieved is $\sim$0.35 amu.

The observed ACR ^{22}Ne/^{20}Ne ratio, $0.085^{+0.047}_{-0.033}$, cannot be compared directly to similar observations at different times because of differing contamination from galactic cosmic rays, which have ^{22}Ne/^{20}Ne $= 0.67$ (Wiedenbeck and Greiner, 1981). We have derived corrections for GCR contributions for this observation and the observation of Smith and McDonald (1983), both of which cover essentially the same energy interval. The only other reported measurement is that of Mewaldt et al. (1984), and it is an upper limit ($\lesssim$0.36) in the 5-30 MeV/nuc interval.

We have also made corrections for the expected spectral energy shift and acceleration and propagation differences (see Cummings and Stone, 1990), in order to derive the ^{22}Ne/^{20}Ne ratio for the ACR source material.

Table 1 shows the results of the correction process. The solid line in Figure 1 was taken to be the galactic cosmic ray Ne spectrum for the 1986-88 time period. A similar power-law approximation was used for the Smith and McDonald data. We assumed that modulation does not change the galactic cosmic-ray ^{20}Ne : ^{21}Ne : ^{22}Ne ratios, which were taken to be $1:0.25:0.67$ (Wiedenbeck and Greiner, 1981). For the energy shift correction, we used the power-law shown in Figure 2 of Cummings and Stone (1990) for both data sets. The appropriate power-law approximation to the ACR Ne spectrum was used to derive the magnitude of this correction factor (Figure 1 for this work). Similarly, for acceleration and propagation differences, we used Figure 3 of Cummings and Stone (1990). We have used Poisson statistics to derive asymmetric uncertainties on the quantities. We note that for the Smith and McDonald data, the resulting observational uncertainty is somewhat larger than their reported value ($0.17^{+0.14}_{-0.09}$ versus $0.17^{+0.07}_{-0.07}$).

Of the seven ^{22}Ne events we observe in the 1986-88 period, only 1.7 are expected to be from galactic cosmic rays. On the other hand, the four ^{22}Ne events observed in the 1977-79 data set are likely dominated by galactic cosmic rays.

In Figure 3 we plot the ACR-source ^{22}Ne/^{20}Ne ratio for this work and for that of Smith and McDonald (1983), along with the ratio in other samples of the solar system. This is the first explicit attempt to derive the ACR-source neon isotopic composition and our measurement in 1986-88 represents a significant improvement in the knowledge of the ACR-source ^{22}Ne/^{20}Ne ratio. However, it is not sufficiently precise to distinguish between the solar wind (Geiss et al., 1972) and the neon-A (Podosek,

1978) values. Our result is also consistent with that derived for the solar corona from solar energetic particle measurements, $0.131^{+0.032}_{-0.024}$ (Mewaldt and Stone, 1989).

Discussion. The observation reported here indicates that the isotopic composition of ACR neon source material is similar to that of other solar system samples, including the solar wind, solar corona, and meteoritic neon-A. Cummings and Stone (1990) have derived elemental abundances of the very local interstellar medium for N, O, and Ar from observations of ACR He, N, O, Ne, and Ar which are in reasonable agreement with solar system values (Grevesse and Anders, 1988). This latter work assumed that the anomalous component is indeed a sample of the very local interstellar medium. If so, the VLISM is apparently solar-like, both elementally and isotopically. If the anomalous component does derive from the inward flowing interstellar neutral gas, then the composition of the source of galactic cosmic rays differs from that of the VLISM.

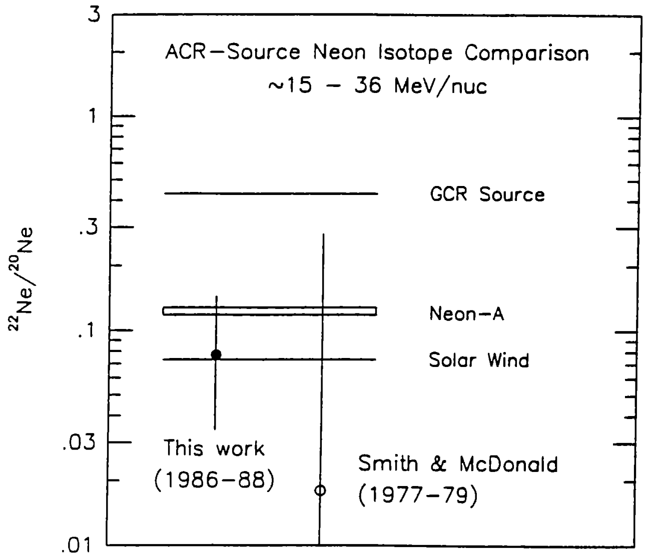

Figure 3. Comparison of the isotopic composition of ACR-source material with that of other samples of matter.

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