X-660-73-392
PREPRINT

NASA TM X- 70566

THE ANOMALOUS ABUNDANCE OF COSMIC RAY NITROGEN AND OXYGEN NUCLEI AT LOW ENERGIES

F. B. McDONALD
B. J. TEEGARDEN
J. H. TRAINOR
W. R. WEBBER

DECEMBER 1973

GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

(NASA-TM-X-70566) THE ANOMALOUS ABUNDANCE OF COSMIC RAY NITROGEN AND OXYGEN NUCLEI AT LOW ENERGIES (NASA) 15 p HC $3.00 CSCL 03B

N74-15475

Unclas
G3/29 27038

THE ANOMALOUS ABUNDANCE OF COSMIC RAY NITROGEN AND OXYGEN NUCLEI AT LOW ENERGIES

BY

F. B. McDonald
B. J. Teegarden
J. H. Trainor

NASA Goddard Space Flight Center
Greenbelt, Maryland

and

W. R. Webber

Department of Physics
University of New Hampshire
Durham, New Hampshire

December 1973

Abstract

Recent measurements using the Goddard-University of New Hampshire cosmic ray telescope on the Pioneer 10 spacecraft have revealed an anomalous spectrum of Nitrogen and Oxygen nuclei relative to other nuclei such as He and C, in the energy range 3-30 MeV/nuc. The intensity of Nitrogen and Oxygen nuclei is enhanced by a factor of up to 20 relative to their abundance in galactic or solar cosmic rays. It is argued that this is most likely a new extra-solar component of cosmic rays.

I. INTRODUCTION

In the past many suggestions have been made that cosmic rays originate in several different types of sources in the galaxy. If this is so, one might expect compositional or spectral changes to occur in the primary radiation as a function of energy as one or another of these sources becomes dominant. To date no clear evidence for source related compositional changes has been observed although it is possible that this type of explanation will be required for the compositional changes recently observed at higher energies (Ormes et al. 1973, Smith et al. 1973, Juliusson 1973, Webber et al. 1973). At low energies (i.e. 1-30 MeV/nuc) the effects of ionization loss in the interstellar medium insure that a more local region of space is sampled and hence the presence of nearby sources could be detected. Observing the low-energy component is, however, made difficult by severe modulation within the solar system and contamination by solar cosmic rays. In 1972, the return of the galactic cosmic rays in the inner solar system to solar minimum conditions and the launch of Pioneer 10 toward Jupiter coincided to make possible the measurements of the low-energy cosmic-ray charge spectra during solar quiet times.

In this paper we report dramatic differences in the low-energy spectra of nitrogen and oxygen relative to other nuclei as obtained from the Goddard-University of New Hampshire cosmic ray experiment on the Pioneer 10 spacecraft. Arguments are presented to suggest that this is a galactic component rather than a solar one, and it is presumably from a source which is rich in these two elements.

II. EXPERIMENTAL RESULTS

Because of the low intensity of the heavier cosmic-ray nuclei, and the small geometrical factor of the cosmic ray telescope, it is necessary to sum over long periods in order to obtain adequate statistics for these nuclei. The cosmic ray telescope and the techniques of analysis for this experiment have already been described (Trainor 1972). The data reported here covers the period March 1972 to March 1973. A two dimensional dE/dx x E matrix of $Z \geq 2$ nuclei events obtained during this time period is shown in Fig. 1. The differential energy spectrum for the different nuclei are obtained directly from this matrix data (Fig. 2). At energies above ~30 MeV/nucleon the spectra of all of the nuclei follow the spectral behavior already well established at higher energies and interpreted in terms of a single galactic component. Below ~30 MeV/nucleon the oxygen and nitrogen spectra rise abruptly and at ~8 MeV/nucleon the abundance of O is now at least a factor ~20 times that of C, whereas in the normal galactic radiation at higher energies this factor is ~1. It is clear that there are sudden and spectacular spectral differences between C and He on one hand and between N or O and He on the other in this energy range. The data on B, Ne and Mg nuclei (Table I) is not as statistically accurate as that for N and O but it is nevertheless clear that these nuclei do not show the same enhancement as N and O. In fact, within statistics their behavior at low energies is similar to carbon. The combined C+N+O flux reported here is in good agreement with the M nuclei (C+N+O) flux reported by Mogro-Campero et al. (1973) and Price et al. (1973) for a portion of the period of our measurement.

Another way of showing these changes in composition is to present the He/C, He/O, and He/N ratios as a function of energy (Fig. 3). The decrease in the C/He ratio with decreasing energy could be consistent with an energy-independent source composition after correcting for the effects of energy loss due to ionization in the interstellar material. The O/He and N/He ratios cannot be accounted for by interstellar propagation effects and imply either a strongly energy-dependent source composition or the presence of a nearby source rich in oxygen and nitrogen. The splitting of the carbon and oxygen spectra had previously been noted at ~20 MeV/nucleon by the Goddard group using OGO-V data (Teegarden et al. 1969). However, the extended energy range and observing time of the Pioneer telescope reveals more clearly the dramatic change in the cosmic ray composition between 8 and 30 MeV/nucleon.

Solar cosmic rays can constitute an important background problem in the low-energy region. To eliminate this a very careful selection of times must be made to assure that solar cosmic rays are not obviously present. This is accomplished by requiring that the 10-20 MeV proton intensity measured on the same experiment be essentially at background level. In general, it has been found that with such a strict requirement on solar cosmic ray protons, the presence of still heavier nuclei is even more effectively discriminated against. With this requirement ~240 days defined as "quiet" from the solar cosmic-ray point of view are found and are available for constructing the pulse-height matrix in Figure 1. The observed helium spectrum for these same periods is essentially flat above ~5 MeV. This is characteristic of a galactic spectrum and supports the idea that solar cosmic-ray protons and helium nuclei are not present in any detectable numbers above ~5 MeV/nucleon during the selected periods. The continuously decreasing carbon nuclei intensities down to ~5 MeV/nucleon also make it clear that no detectable solar carbon nuclei are present. In addition, preliminary analysis indicates the presence of positive gradients for He and O in the 8-30 MeV/nucleon interval which are difficult to reconcile with a solar origin for these particles. This gradient data is still quite preliminary and will be followed by a more detailed account later.

Price et al. (1973) and several other groups have reported the systematic enhancement of heavier nuclei in solar events. This enhancement increases with Z through the trans-iron group ($Z \geqq 32$) and with decreasing energy down to ~0.1 MeV/nucleon. The effect, however, is not present at energies greater than 10 MeV/nucleon for elements between He and Iron. This is clearly not consistent with the selective increase of oxygen and nitrogen reported here.

A further question immediately arises; what happens at still lower energies? We note that the He spectrum rises rapidly between 4 and 6 MeV/nucleon. In addition, we show data on low-energy C and O nuclei published by Hovestadt et al. (1973). These IMP VII data are obtained from a 13 day period in October 1972, which is a small subset of the Pioneer 10 period of analysis. Therefore, time variations of this component, if they exist, could complicate the comparison of these two sets of measurements. With this proviso in mind we notice that, in fact, our data joins smoothly with theirs. This extension to lower energies reveals that the new oxygen component has a broad intensity maximum extending from 6 down to at least 2 MeV. For carbon there are only upper limits over this range but they are still considerably less than the oxygen values. Below 1 MeV Hovestadt et al. (1973) report that oxygen and carbon are roughly equal in abundance and have steep energy spectra. Both of these factors would suggest this very low energy region is dominated by solar particles. We would tentatively ascribe the same origin to the rapidly rising He spectrum below 5 MeV/nucleon.

III. DISCUSSION

Let us now consider what might be the source for this new component of N and O nuclei in the 3-30 MeV/nucleon range. We have already seen that this composition is totally unlike that observed in any solar cosmic-ray event. Furthermore, the apparent positive gradients for O nuclei argue against a solar origin since normally large negative gradients of solar particles would be expected as one moves away from the sun. These factors indicate very strongly the enhanced N and O is of extra-solar origin. At this point in time our very preliminary survey has not revealed any obvious astrophysical source for these cosmic ray particles.

The question then arises, what effect does solar modulation have on the abundance ratios that we observe in the inner solar system. Let us assume that the modulation can be described by the same Green's function for all particles of identical A/Z. Then it can be shown that if the observed abundance ratio as a function of energy/nucleon of particles with the same A/Z has a certain maximum value, Γ, there must be some energy at which the interstellar ratio is $\geq \Gamma$. This means, for example, that the interstellar O/C ratio must at some energy be at least as large as 20. However, current modulation theory is not adequate to allow us to accurately estimate the magnitude of the energy loss of these particles in interplanetary space. Since the energy spectra of these particles outside the heliosphere is not know, it cannot be determined yet whether this is a low-energy phenomena produced by a unique nearby source or whether this represents a higher-energy population extending throughout the galaxy. Later measurements by Pioneer 10 and 11 at large heliocentric distances will provide further data on this question.

REFERENCES

Comstock, G. M., Fan, C. Y., and Simpson, J. A., 1967, Ap. J., 155, 609.

Hovestadt, D., Vollmer, O., Gloeckler, G., and Fan, C. Y., 1973, Phys. Rev. Letters, 31, 650.

Juliusson, E., 1973, 13th International Cosmic Ray Conference, Conference Papers, Denver, Colorado, 1, 178.

Mogro-Campero, A., Schofield, N., and Simpson, J. A. 1973, 13th International Cosmic Ray Conference, Conference Papers, Denver, Colorado, 1, 140.

Ormes, J. F., Balasubrahmanyan, V. K., and Arens, J. F. 1973, 13th International Cosmic Ray Conference, Conference Papers, Denver, Colorado, 1, 157.

Price, P. B., Chan, J. H., Crawford, H. J., and Sullivan, J. D. 1973, 13th International Cosmic Ray Conference, Conference Papers, Denver, Colorado, 2, 1479.

Price, P. B., Chan, J. H., O'Sullivan, D., and Thompson, A. 1973, 13th International Cosmic Ray Conference, Conference Papers, Denver, Colorado, 1, 146.

Smith, L. H., Buffington, A., Orth, C. D., and Smoot, G. F. 1973, 13th International Cosmic Ray Conference, Conference Papers, Denver, Colorado, 1, 177.

Teegarden, B. J., McDonald, F. B., Balasubrahmanyan, V. K. 1969, Proceedings of the 11th International Cosmic Ray Conference, Budapest, 1, 345.

Trainor, J. H., 1972, in Significant Accomplishments in Sciences, NASA Pub. SP-331, 38.

Webber, W. R. "Cosmic Ray Charge Measurements - A 1972 Summary" Inter-American Seminar on Cosmic Rays, Sao Paulo, Brazil, October 1972, to be published.

Webber, W. R., Lezniak, J. A., Kish, J. C., Damle, S. V., Nature 241, 96, 1973.

TABLE I

RATIO	PIONEER 10 ENERGY INTERVAL (MeV/nuc)	PRESENT WORK	WEBBER[/] (>1 GeV/nuc)
B/He	8.3 - 30	.0026 ± .0013	.0097 ± .006
C/He	9.0 - 30	.0067 ± .0022	.031 ± .002
N/He	7.3 - 30	.022 ± .004	.008 ± .001
	7.3 - 10.6*	.089 ± .024	
	10.6- 17.4*	.025 ± .007	
O/He	7.3 - 30	.091 ± .008	.028 ± .001
	7.3 - 10.6*	.42 ± .06	
	10.6- 17.4*	.109 ± .015	
Ne/He	12 - 30	.0038 ± .0017	.0049 ± .0004
Mg/He	13.4- 30	<.0017	.0057 ± .0004
Si/He	14.5- 30	<.0018	.0038 ± .0003

*Ratios in smaller energy intervals are shown for O and N to illustrate the increased enhancement at lower energies

/Webber 1972.

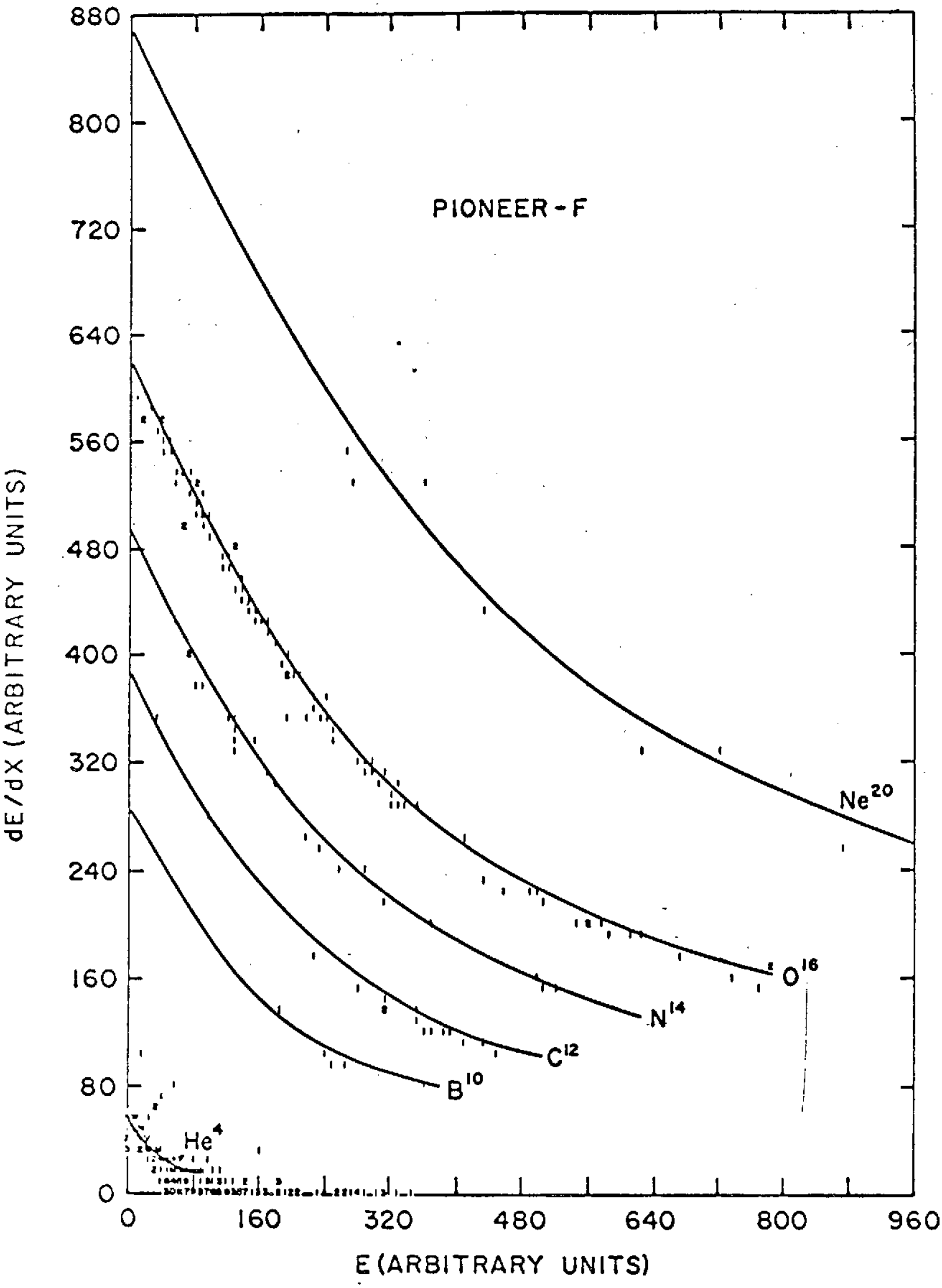
FIGURE CAPTIONS

1. dE/dx vs. E plot of Pioneer 10 data showing various particle tracks. The spectral differences between oxygen and carbon are obvious even in this raw data.

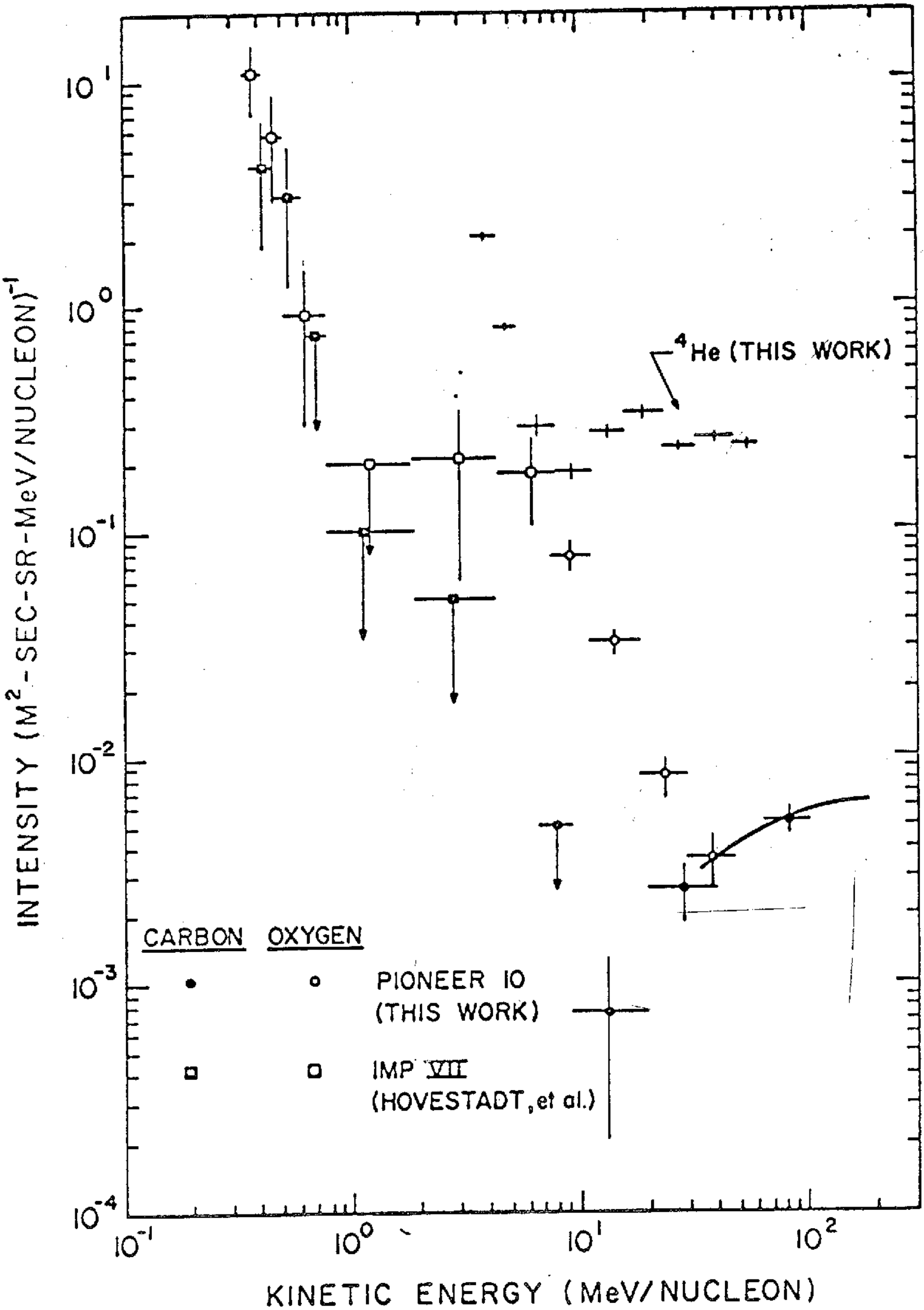
2. C, O, and ^{4}He spectra. The C and O spectra at higher energies derived from the Goddard cosmic-ray telescope on IMP VII are indicated by the solid line.

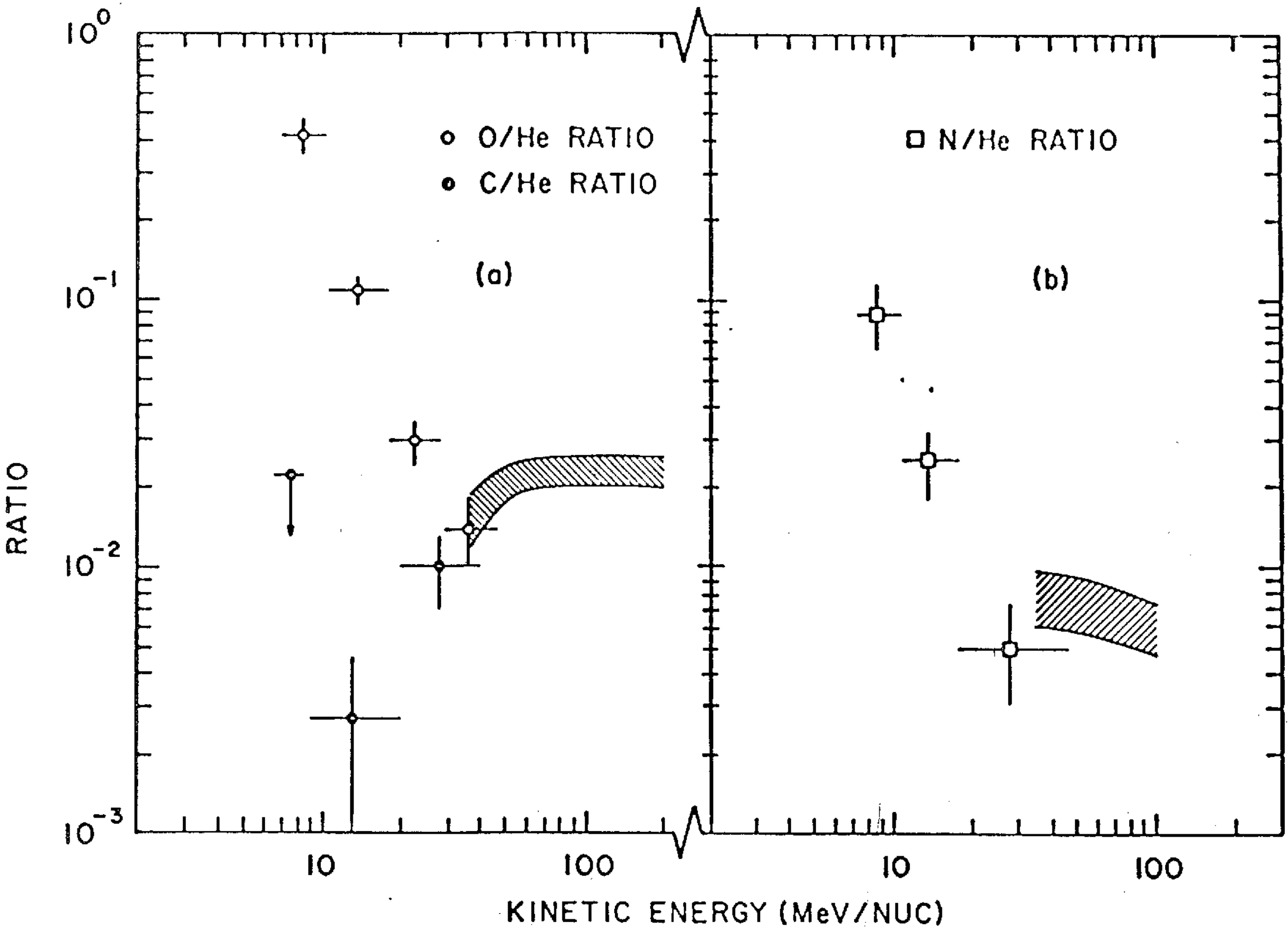
3. a. O/He and C/He ratios as a function of energy/nucleon. Cross-hatched region indicates the O/He and C/He ratios at higher energies derived from the Goddard cosmic-ray telescope on IMP VII.

   b. N/He ratio as a function of energy/nucleon. Cross-hatched region indicates the N/He ratio derived from the data of Comstock et al. (1969) taken at the last solar minimum.



PIONEER-F
Ne^{20}
O^{16}
N^{14}
C^{12}
B^{10}
He^{4}
dE/dX (ARBITRARY UNITS)
E (ARBITRARY UNITS)
0
80
160
240
320
400
480
560
640
720
800
880
960


INTENSITY (M^2-SEC-SR-MeV/NUCLEON)$^{-1}$
KINETIC ENERGY (MeV/NUCLEON)
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{2}
^{4}He (THIS WORK)
CARBON
OXYGEN
PIONEER 10
(THIS WORK)
IMP VII
(HOVESTADT, et al.)



10^0
10^{-1}
10^{-2}
10^{-3}
RATIO
O/He RATIO
C/He RATIO
(a)
N/He RATIO
(b)
10
100
10
100
KINETIC ENERGY (MeV/NUC)

-12-