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George Gloeckler

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George Gloeckler
Department of Physics and Astronomy, University of Maryland
College Park, Maryland 20742 USA

1. Introduction. The composition of energetic particles is useful in identifying their sources of origin and carries essential information on acceleration mechanisms within these sources. Initial studies of solar flare particles found the composition above ~ 30 MeV/nuc to be reproducible from one solar flare event to the next and similar to the abundances of elements in the solar atmosphere. These results were consistent with acceleration processes which did not depend on the nuclear charge of the particles and provided the means of filling in gaps in our knowledge of the composition of the solar atmosphere.

Today, we are confronted with a diversity and variability in the composition of elements and isotopes of solar origin which was entirely unexpected and for which we have no satisfactory explanation at present. It is not unusual to find, for example, ^{3}He more abundant than ^{4}He and iron more abundant than oxygen. It is especially for nuclei below 10 MeV/nuc and in the small intensity increase where the composition anomalies are most pronounced.

Our notion that the sun alone in our solar system can accelerate particles must be abandoned in light of evidence that Jupiter is and earth may be sources for some of the low energy particles we observe. Furthermore, it is likely that large scale acceleration of ions to energies of tens of MeVs may, in fact, be taking place in the outer regions of the interplanetary medium.

More than 50 papers presented at this Conference dealt with the composition of low energy particles. The topics can be divided roughly into two broad categories. The first is the study of the energy spectra and composition of the steady or "quiet-time" particle flux, whose origin is at this time unknown. The second category includes the study of particles and photons which are associated with solar flares or active regions on the sun. Further subdivisions within the two categories along with a tabulation of conference papers which addressed each of the subtopics are given in Table 1.

2. Experimental Techniques. Three different detection techniques are used to measure the composition and energy spectra of low energy particles. These methods have been summarized by Hovestadt (1973). The chemical abundance may be determined with large-area passive track detectors which are sensitive to particles heavier than protons in the energy range from a few tens of keV/nuc to over a 100 MeV/nuc. Chemical and isotopic compositions are also measured with active dE/dx vs E counter telescopes where the use of either thin solid state detectors or thin, large-area proportional counters as the ΔE element allows separation of individual chemical elements at energies as low as several hundred keV/nuc. Charge states of ions are measured directly by electrostatic analyzer experiments which are sensitive from ~ 10 keV/nuc to ~ 1 MeV/nuc. Improvements in the resolution, sensitivity and low energy

Table 1. LOW ENERGY PARTICLE COMPOSITION

TOPIC	CONFERENCE PAPERS
"QUIET-TIME" COMPOSITION	
. Protons and Helium	OG10-5,6,7; OG7-2,5; H-4,5
. Anomalous He, N, O, and Ne	OG10-5,8,9,10,11,12;OG7-10,P-5;H-1,5
. Heavy Particles in Magnetosphere	OG10-13,14,15,16
. Jovian Electrons	OG10-1,2,3,P-9
SOLAR PARTICLE COMPOSITION	
. ^{3}He rich Events	SP2.1-13,14,16,17; SP3-8,H-3,8
. Heavy Ion Enriched Events	SP2.1-10,13,16
. Nuclear Abundances	SP2.1-3,5,6,9
. Temporal and Spatial Variations	SP2.1-2,8,12
. Statistical Studies	SP2.1-1,4
. Charge States	SP2.1-4
. Nuclear Reaction Products (Isotopes, positrons, γ-rays)	SP2.1-16; SP3-4,8,9
. Particle Production and Acceleration in Flares	SP1-1,2; SP2.1-4,7,15 SP3-1,2,3,5,6,7,10; OG10-4

response of the detectors have contributed to the exploration of new energy and intensity regimes and led to the results which are summarized below.

3. The Composition and Energy Spectra During Quiet Times. Composition measurements of quiet-time particles revealed the most surprising results. Garcia-Munoz, Mason and Simpson (1973) were first to point out that helium was more abundant than protons between about 10 and 40 MeV/nuc. Hovestadt et al. (1973) reported the unusual spectral feature of a hump for oxygen between ∿ 2 and 10 MeV/nuc and a significantly reduced abundance of carbon. Measurements by the Goddard-New Hampshire group (McDonald et al., 1974) above 8 MeV/nuc showed that nitrogen as well as oxygen were overabundant compared to carbon. The origin of these particles still remains unknown although interesting possibilities have been suggested.

Protons and Helium. Measurements of protons and helium nuclei below a few MeV/nuc during quiet times are difficult because of the infrequency and short duration of quiet-time periods and background problems associated with one parameter measurement techniques commonly used. The first consistent set of quiet-time proton and alpha measurements extending in energy to ∿ 300 keV/nuc have been reported at this Conference.

The results of Gloeckler et al. (OG10-5), which are based on a 2 parameter dE/dx vs E analysis technique are shown in Figure 1 along with measurements of Mewaldt et al. (OG10-6) and Krimigis et al. (OG10-7). The helium spectrum shows two anomalous features. Between ∿ 4 to 50 MeV/nuc the spectrum is flat and the helium abundance exceeds that of protons. This anomaly has been discussed extensively in the literature (Garcia-Munoz et al.,1973, 1975; Van Hollebeke et al.,1973; Mewaldt et al., 1975) and at this Conference

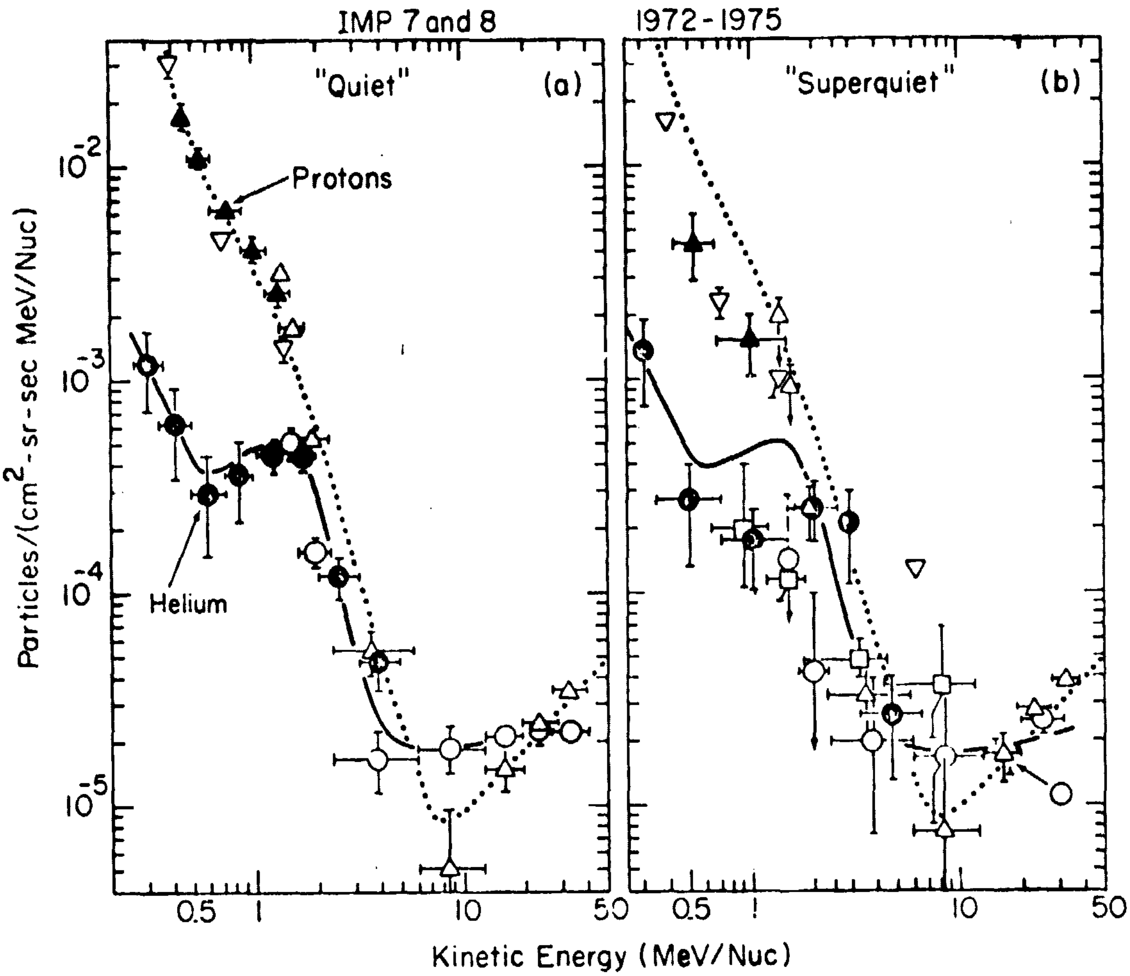

Fig. 1.-Differential energy spectra for protons and helium nuclei during (a) "quiet" and (b) "super-quiet" time periods in 1972-1975. The data are from: ▲ (protons) ●(helium), Gloeckler et al., OG10-5; ▽(protons) □(helium), Krimigis et al., OG10-7; △(protons) ○(helium), Mewaldt et al., OG10-6. The helium spectrum has two anomalous features: a hump between ~1 and 3 MeV/nuc and a flat portion between ~4 and 50 MeV/nuc where the intensity of helium exceeds the proton intensity.

(Garcia-Munoz et al., OG7-5; Mewaldt et al., OG10-6). At about 1-3 MeV/nuc there is a hump in the spectrum as is evident from the data of Gloeckler et al. (1976, OG10-5). Protons have a more normal spectrum with perhaps a hint of a hump at ~ 2 MeV. The energy spectra during the most quiet or "super-quiet" times are given in the right-hand panel of Figure 1 and show that the helium hump at ~ 1-3 MeV/nuc is still noticeable although its intensity is reduced.

Studying the time variation of the quiet-time proton to alpha ratio between 1.3 and 2.3 MeV/nuc Mewaldt et al. (OG10-6) find this ratio to be highly variable, ranging from 2 to 20, with no correlation between the intensities of protons and alphas.

Although there is agreement in the measurements of the energy spectra of these very low energy protons and helium nuclei, there is no general agreement on their origin. Gloeckler et al. (1975, OG10-5) suggest that protons between 0.4 and 1.5 MeV and helium below ∿ 0.5 MeV/nuc are solar in origin. A similar conclusion is reached by Mewaldt et al. (OG10-6) for protons and alphas above 1.3 MeV/nuc, although they cannot exclude other sources. Krimigis et al. (OG10-7) argue, however, that a large fraction of low energy protons comes from the earth's magnetosphere and they further suggest that Jupiter may produce some of the observed quiet-time protons in the 2-20 MeV range.

The source for the helium in the hump between ∿ 1 and 3 MeV/nuc is even less certain and both a solar and non-solar origin hypothesis are considered by Gloeckler et al. (1975, OG10-5). Results on the radial gradients of these low energy quiet-time particles (Simpson and Tuzzolino, 1973; Witte et al., H-4; Trainor et al., H-5) are at present either in question or very preliminary and thus do not provide any definitive answers on their origin.

Anomalous He, N, O, and Ne. Klecker et al. (OG10-8), von Rosenvinge et al. (OG10-9), Mewaldt et al. (OG10-10,11) and Webber et al. (P-5) reported on the energy spectra, abundances, long term intensity variations and radial gradients of low energy elements heavier than helium during quiet times. The combined results on the energy spectra are shown in Figure 2. The hump in the spectrum of oxygen (see left-hand panel of Figure 2) between ∿ 1 and 10 MeV/nuc discovered by Hovestadt et al. (1973) is clearly visible and for the first time a finite flux of carbon has been measured in the low energy region of the oxygen enhancement (Klecker et al., OG10-8). Allowing for the large statistical uncertainties there is reasonable agreement among the measurements taken near earth. The higher fluxes observed by Webber et al. (P-5) at distances from 1 to 5 AU are consistent with a positive gradient for oxygen of about 20% per AU they measured. In the right-hand panel of Figure 2 are shown the energy spectra of nitrogen and neon along with curves representing the spectra of H, He, C and O. It should be noted that Ne as well as nitrogen are overabundant. In fact, the composition at ∿ 10 MeV/nuc deduced from these curves is particularly unusual. He is more abundant than oxygen, neon and nitrogen are each more abundant than carbon. The intensity of oxygen is nearly equal to that of protons.

The relative abundances of elements from He to Fe in the anomalous component between ∿ 3 and 30 MeV/nuc are compared with the galactic cosmic ray composition at ∿ 100 MeV/nuc in Figure 3. There is very good agreement among the various measurements taken near earth. Furthermore, the Pioneer 10 and 11 results (Webber et al., P-5) are consistent with the near earth measurements and thus imply that the relative abundances remain unchanged over a large range of heliocentric distance. Normalizing the galactic composition to carbon, the striking overabundance of He, N, O and now also Ne is quite evident.

What can we say about the origin of these particles? Nearly everyone agrees that they are not accelerated at or near the sun. This conclusion is supported by the following evidence:

(1) There is no correlation between the intensity of the anomalous oxygen and the intensity of low energy (< 1.5 MeV) protons which most probably come from the sun (Klecker et al., OG10-8). On the other hand, there is a definite correlation with neutron monitor intensities (von Rosenvinge et al., OG10-9; Mewaldt et al., OG10-11).

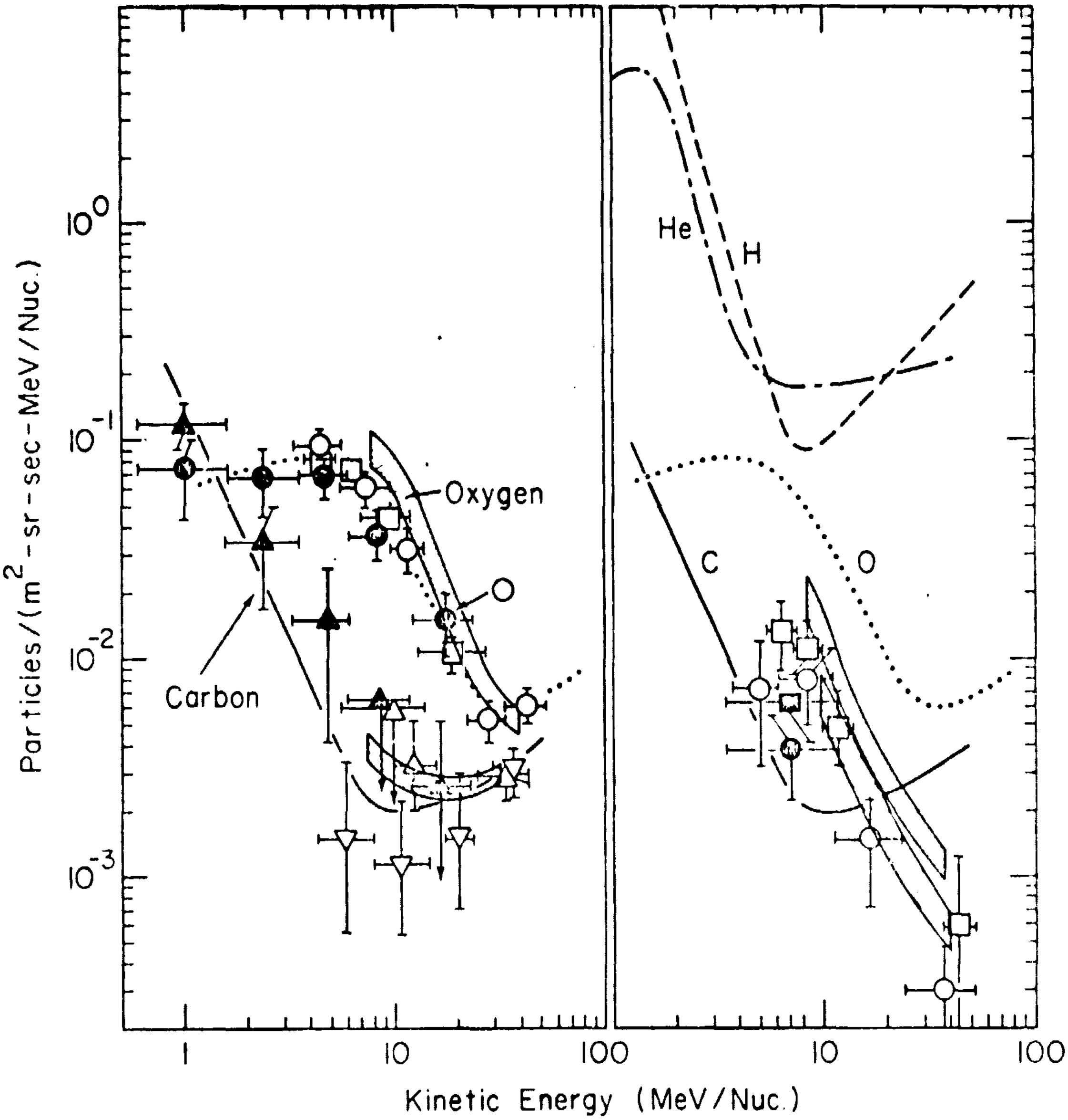

Fig. 2.-Differential energy spectra of heavy nuclei of the anomalous component measured during quiet-time periods in 1972-1975. The smooth curves are shown for reference with the spectra for H and He given in the right-hand panel taken from Figure 1(a). The data are from (a) left-hand panel: ▨ (oxygen) ▧ (carbon), Webber *et al.*, P-5; ● (oxygen) ▲ (carbon), Klecker *et al.*, OG10-8; □ (oxygen) ▽ (carbon), Mewaldt *et al.*, OG10-10; ○ (oxygen) △ (carbon), von Rosenvinge *et al.*, OG10-9. (b) right-hand panel: ▨ (nitrogen) ▧ (neon), Webber *et al.*, P-5; ■ (nitrogen) ● (neon), Klecker *et al.*, OG10-8; □ (nitrogen), Mewaldt *et al.*, OG10-10; ○ (neon), von Rosenvinge *et al.*, OG10-9. The large overabundance of oxygen, nitrogen and neon compared to carbon and of helium compared to protons is evident in the energy range of ~3 to 30 MeV/nuc.

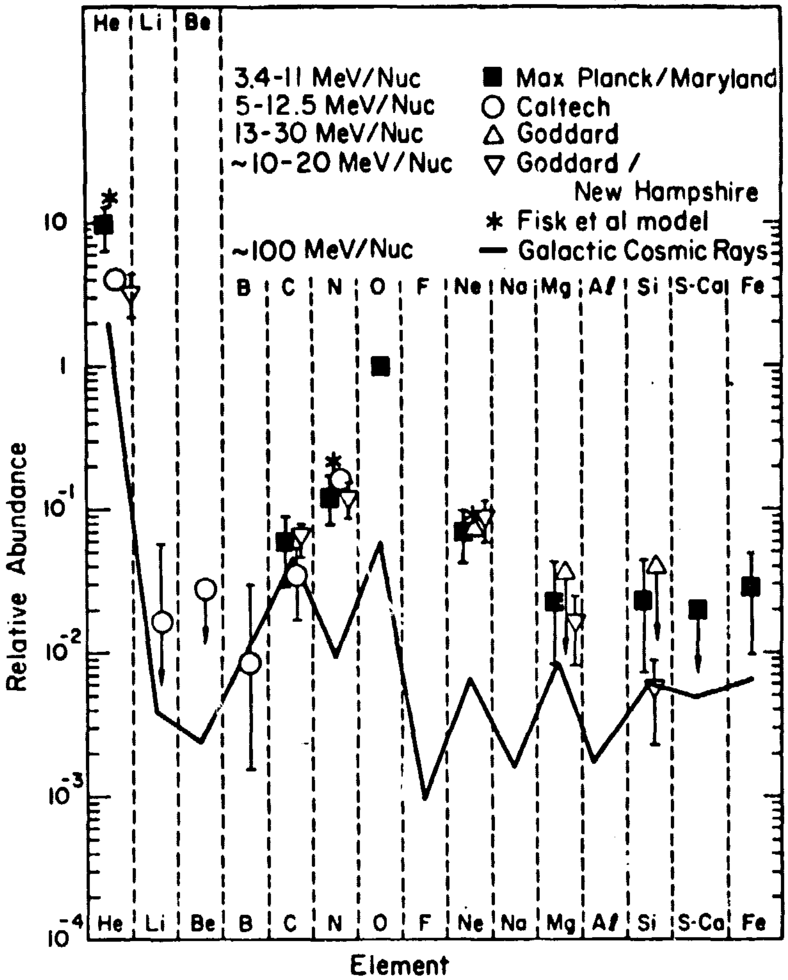

Fig. 3.-Comparison of the relative abundances in the anomalous component between ∿3 to 30 MeV/nuc with the composition of galactic cosmic ray at ∿100 MeV/nuc (solid curve) and abundances (*) deduced from the model of Fisk et al. (1974) for He, N, O and Ne. The individual measurements and the composition based on the Fisk et al. model have been normalized at oxygen, the galactic abundances have been normalized at carbon. The data are from: ■ Klecker et al., OG10-8; O Mewaldt et al., OG10-10; △ von Rosenvinge et al., OG10-9; ▽ Webber et al., P-5. The elements nitrogen, oxygen and neon in the anomalous component are overabundant by about a factor of 10 compared to the respective elements in the galactic cosmic rays.

(2) The intensity of the anomalous oxygen increases with heliocentric distance at a rate of about 20% per AU (Webber et al., P-5).

(3) The composition of the anomalous component, is unlike that of solar particles (see, for example, Klecker et al., OG10-8).

If these particles are non-solar are they galactic? If this were the case the galactic source would have to have a highly unusual composition and our theories of solar modulation would have to be drastically revised. Depletion of carbon and large relative abundances of ^{13}C, ^{15}N and ^{17}O may indeed occur in certain white dwarf stars as suggested by Hoyle and Clayton (1974). Any source of this kind is, however, ruled out because the anomalous component consists predominantly of the isotopes ^{12}C, ^{14}N and ^{16}O (Mewaldt et al., OG7-10; Webber et al., P-5).

A more realistic mechanism which accounts for the overabundance of He, N, O and Ne in the anomalous composition and is consistent with the isotopic composition observed was proposed by Fisk, Koslovsky and Ramaty (1974) and summarized and extended by Fisk (OG10-12) at this Conference. In this model interstellar neutral particles, mainly H, He, N, O and Ne, are ionized in and picked up by the solar wind attaining energies of ∿ 1 keV/nuc. A small fraction of these newly ionized particles is further accelerated to the observed energies (∿ 10 MeV/nuc) in the outer solar system by presumably long-wave, magnetosonic turbulence. A firm prediction of the Fisk et al. model is that particles accelerated in this fashion are singly charged and hence are modulated only slightly as they re-enter the inner solar system. Indirect evidence for the low charge state of oxygen is provided by measurements of the relative intensity variations of oxygen and helium shown in Figure 4. The intensity variation observed is most consistent with the hypothesis that the particles are singly charged (von Rosenvinge et al., OG10-9).

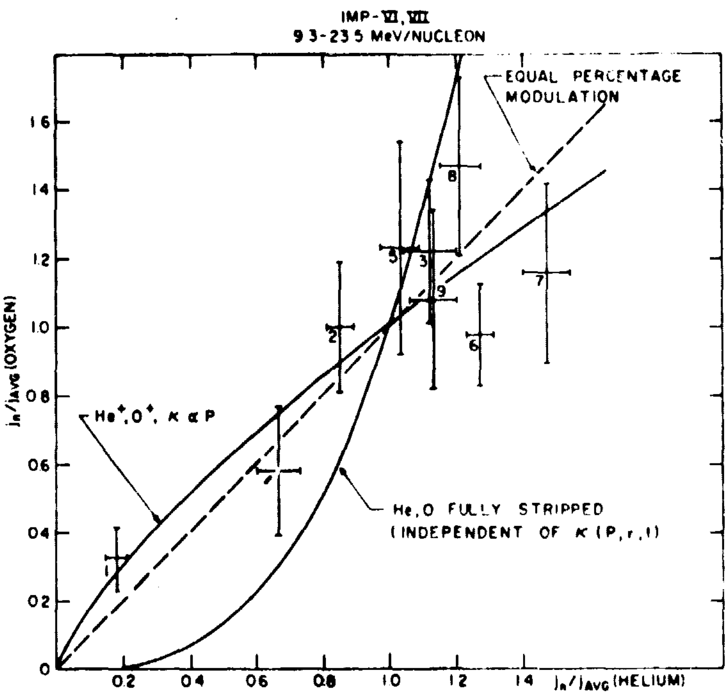

Fig. 4.-A regression plot for the anomalous oxygen and helium between 9.3 and 23.5 MeV/nuc. Points 1 and 9 correspond to nine quiet-time intervals in 1971 to 1974. The data are consistent with equal percentage modulation for oxygen and helium (dashed line) and indicate a reasonable fit to the theoretical curve based on the force-field approximation (Gleeson and Axford, 1968) and the hypothesis that helium and oxygen are singly charged. (Figure taken from von Rosenvinge et al., OG10-9.)

4. Heavy Particles of an Unknown Origin in the Earth's Magnetosphere. The Skylab Mission provided the opportunity to expose at an altitude of ∿ 430 km for ∿ 70 days and then recover large area track recording detectors. Biswas et al. (OG10-13,14), Krätschmer (OG10-15) and Chan and Price (OG10-16) reported unexpected results based on the exposure of their detectors on Skylab. IMP 7 and 8 satellite observations showed that during the time of the Skylab exposure (November 22,1973 to February 3,1974) no significant solar flare particle emission occurred. Furthermore, the geomagnetic cutoff of ≳ 50 MeV/nuc at the orbit of Skylab prevented low energy heavy nuclei from reaching the track detectors. It was therefore surprising to see substantial fluxes of heavy particles in the inner region of the magnetosphere. To illustrate the Skylab results the measurements of oxygen and heavier elements by Chan and Price (OG10-16) are shown in Figure 5. Krätschmer (OG10-16), measured the energy spectra of Fe,Ca and Si down to ∿200 keV/nuc and Biswas et al. (OG10-13,14), reported abundances of B,C,N,O,Ne,Ca and Fe at 10-30 MeV/nuc. The energy spectra rise steeply with decreasing energy, and for Si,Ca and Fe the spectra continue to rise to ∿0.2 MeV/nuc (Krätschmer, OG10-15). The relative abundances reported by Chan and Price (OG10-16) seem to be most consistent with those of

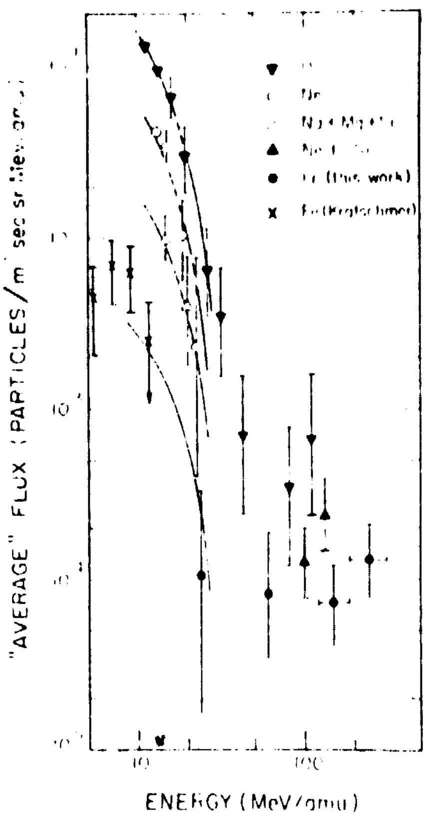

Fig. 5.-Time-averaged energy spectra of heavy elements between ∿10 and 100 MeV/nuc measured on Skylab in the inner regions of the earth's magnetosphere. The intensities observed are unusually high and may indicate that heavy ions are continuously accelerated to energies of ∿20 MeV/nuc in the magnetosphere. (Figure taken from Chan and Price, OG10-16.)

the solar corona or the solar wind, and in particular, imply that the source of these particles is neither galactic nor ionospheric. To explain the high intensities observed requires that either (1) interplanetary particles have an easy access to these inner regions of the magnetosphere as is suggested by Biswas et al. (OG10-13,14), or (2) that solar wind ions diffuse into and are accelerated in the magnetosphere to the observed energies as is proposed by Chan and Price (OG10-16). The mechanisms required for either of the two suggested alternatives are at present unknown.

5. Jovian Electrons. "Quiet-time" increases in the flux of 3-12 MeV interplanetary electrons have been observed over the years by the Goddard group (McDonald et al., 1972). It was only following the encounter of Pioneer 10 with Jupiter that it became clear (Chenette et al., 1974; Teegarden et al., 1974) that this planet is the source of much of the low energy electron component observed near earth. Four groups have reported observations of Jovian electrons at this Conference and their results may be summarized as follows:

(1) There is a seasonal (∿13 months) as well as a 27 day periodicity in frequency and size of the quiet-time electron increases as is illustrated in Figure 6. (L'Heureux and Meyer, OG10-1; Krimigis et al., OG10-2; Mewaldt et al., OG10-3; Teegarden et al., 1974; McDonald et al., 1972).

(2) The increases are confined to electrons below ∿ 30 MeV (L'Heureux and Meyer, OG10-1) and are observed at energies as low as ∿ 0.2 MeV (Krimigis et al., OG10-2; Mewaldt et al., OG10-3).

(3) The energy spectra of electrons are of the form $E^{-1.5\pm0.3}$ (Krimigis et al., OG10-2; Mewaldt et al., (OG10-3) and similar to the spectra of electrons in the Jovian magnetosphere as reported by McDonald et al., (P-9).

(4) The duration of the electron increases is between 3 to ∿ 20 days (as opposed to ∿ one day for solar electron events) and their time-intensity profiles are different from those of solar flare electrons (Krimigis et al., OG10-2; Mewaldt et al., OG10-3).

(5) Between 1 and 3 AU the gradient for these electrons is ∿ 150% per AU (McDonald et al., P-9).

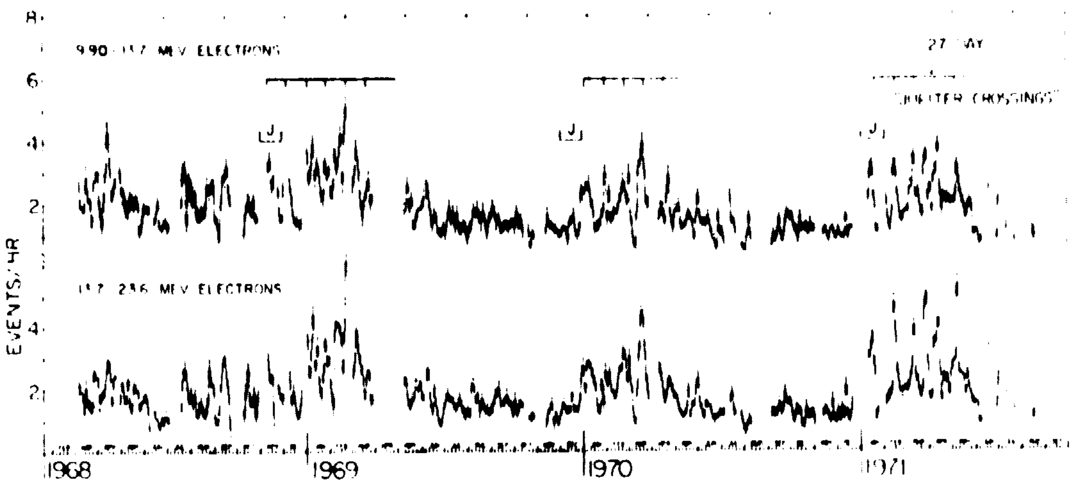

Fig. 6.-Hourly rates vs. time for electrons, with periods of solar activity removed. The frequency and size of the electron increases shows both a seasonal (~13 months) and 27 day periodicity with the onset of the increases corresponding to times (marked J) when earth and Jupiter are on the same nominal magnetic field line. The Jovian origin of these quiet-time electron increases has been established as discussed in the text. (Figure taken from L'Heureux and Meyer, OG10-1).

Two puzzling features of the Jovian electron increases are the long duration of individual increases and the occurrence of these increases for periods of about 4 months after nominal field line connection between earth and Jupiter. One way to account for these characteristics is to assume continuing injection of Jovian electrons on field lines for periods of ~8-15 days after they have passed Jupiter. This would require a reconnection between the Jovian and interplanetary magnetic field lines over distances between ~ 2 to 4 AU, a possibility suggested by both Krimigis et al. (OG10-2) and Mewaldt et al. (OG10-3). The configuration of idealized magnetic field lines intersecting an extended Jovian magnetotail and the orbit of earth is shown in Figure 7 which illustrates how electrons injected on field lines intersecting the Jovian tail (shaded region) will arrive at the orbit of earth over a ~120° spread in solar longitude.

6. Solar Particle Events with Anomalous Compositions. Recent results have indicated that the composition of particles emitted by the sun is frequently highly unusual. The discoveries of the ^{3}He rich events by Garrard et al. (1973) and Anglin et al. (1974) and of the unusually enriched emissions of iron by Gloeckler et al. (1975) confront us with perhaps the greatest puzzles. Work reported at this Conference has established that the occurrence of events with an enriched ^{3}He abundance (R $\equiv$ ^{3}He/^{4}He $\geq$ 0.2) is not uncommon and that ^{3}He can exceed the abundance of ^{4}He by as much as a 8. Furthermore, it has now been established by Hovestadt et al. (SP2.1-13) and Hurford et al. (1975, SP2.1-16) that ^{3}He rich emission is associated with a large overabundance of heavy particles.

^{3}He-rich Events. About 15 instances of intensity increases having an abnormally large abundance of ^{3}He have been reported and are listed in Table 2. Our present knowledge of the characteristics of ^{3}He-rich increases is summarized below.

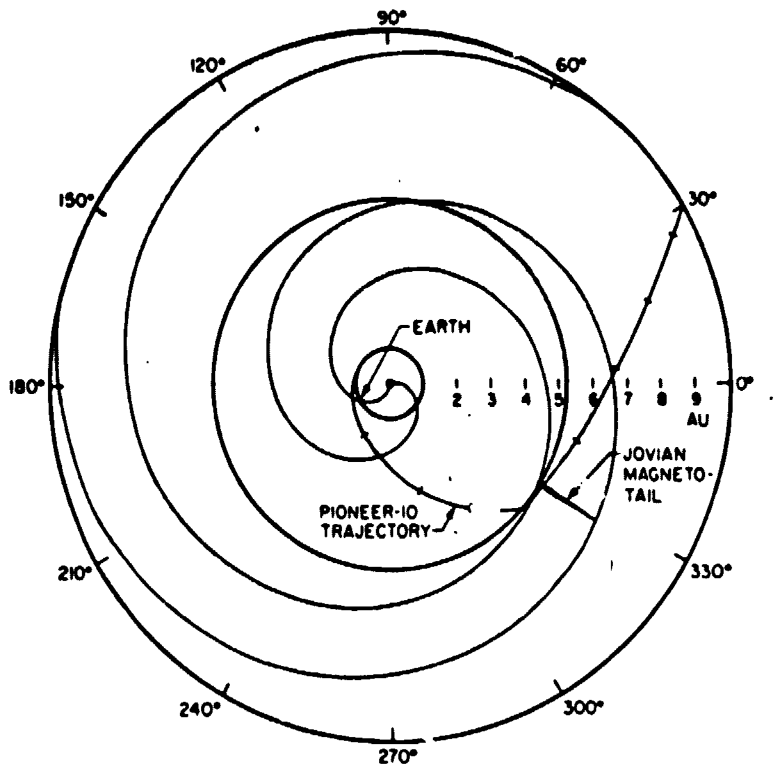

Fig. 7.-Configuration of nominal interplanetary magnetic field lines in the ecliptic plane showing a region of connection between an extended Jovian magnetotail and the orbit of earth. Electrons injected on field lines intersecting the Jovian tail in the shaded region will reach the orbit of earth spread over ~120° in solar longitude and will be observed near earth for periods of ~4 and 5 months. (Figure provided by Mewaldt, Stone and Vogt.)

(1) The frequency of ^{3}He rich increases is about 3 to 4 per year (see Table 2).

(2) ^{3}He rich increases are associated with either weak or no flares. Some may be associated with active regions on the sun. (Hovestadt et al., SP2.1-13; McDonald et al., SP2.1-14; Hurford et al., SP2.1-16).

(3) ^{3}He/^{4}He ratios greater than 0.5 are not uncommon (see Table 2). Ratios as high as 8 have been observed (Hurford et al., SP2.1-16).

(4) ^{3}He enrichment has now been found at energies below 1 MeV/nuc (Hovestadt et al., SP2.1-13).

(5) A ^{3}He rich event has been observed at a heliocentric distance of ~ 0.3 AU by two Helios experiments (Van Hollebeke et al., H-8; Green et al., H-3).

(6) No measurable amounts of deuterium or tritium have been detected in any of the ^{3}He rich events - only upper limits are reported (see Table 2).

Table 2. SOLAR PARTICLE EVENTS WITH A HIGH ^3He ABUNDANCE

Date	$^3He/^4He$	Upper Limits $^2H/^3He$	Upper Limits $^3H/^3He$	H/He	O/Fe	Energy Range (MeV/nuc)	Paper No. and Authors
4/29/68	0.24 ± 0.06	<0.36	<0.17	72 ± 6			
5/ 5/69	0.53 ± 0.06	<0.033	<0.033	16.4 ± 0.8			
5/28/69	1.52 ± 0.01	$<3.6 \times 10^{-3}$	$<1.8 \times 10^{-3}$	1.0 ± 0.5			
5/29/69	0.71 ± 0.06	$<4 \times 10^{-3}$	$<8 \times 10^{-3}$	4.03 ± 0.18			
5/29/69	0.35 ± 0.03	<0.016	<0.011	2.7 ± 0.1			
10/14/69	0.45 ± 0.06	<0.055	<0.023	51 ± 3		~5-19	SP2.1-14 McDonald von Rosenvinge Serlemitsos Balasubrahmanyan
7/30/70	0.45 ± 0.06	<0.011	<0.053	4.4 ± 0.3			
4/ 2/71	0.21 ± 0.04	<0.12	<0.17	87 ± 6			
5/12/71	0.22 ± 0.06	<0.12	<0.06	63 ± 6			
5/12/71	0.40 ± 0.05	<0.06	<0.043	26 ± 1			
5/14/71	0.24 ± 0.08	<0.06	<0.06	9.5 ± 0.8			
6/30/71	0.40 ± 0.07	<0.085	<0.025	86 ± 1			
2/14/73	0.21 ± 0.07			3.1 ± 0.35			
6/29/73	~2	<0.053	<0.053	6.7 ± 2			SP2.1-16 Hurford, Stone, Vogt
9/ 5/73	~6			~1		~3-15	
2/20/74	~0.4			~10			
2/20/74	0.63 ± 0.10			3.2 ± 0.3		~5-19	SP2.1-14 McDonald et al.
2/20/74	0.09 ± 0.02	<0.23	<0.012	9.0 ± 0.3	1.06 ± 0.13	0.6-1.6	SP2.1-13 Hovestadt, Klecker, Vollmer, Gloeckler, Fan
5/ 7/74	1.06 ± 0.15	<0.038	$<9.4 \times 10^{-3}$	5.0 ± 0.4	1.83 ± 0.3		
5/ 8/74	1.3 ± 0.4			2.5 ± 0.5		5-19	SP2.1-14 McDonald et al.
5/ 9/74	~8			~2.3		3-15	SP2.1-16 Hurford et al.
11/30/74	0.64 ± 0.15	<0.078	$<3.2 \times 10^{-3}$	4.3 ± 0.5	1.0 ± 0.5	0.6-1.6	SP2.1-13 Hovestadt et al.

(7) There is no strong correlation between the $^3He/^4He$ and p/α ratios although in most cases of ^3He rich emission the p/α ratio is <10 (see Table 2).

(8) In all cases where heavy nuclei could be measured it was found that iron was as abundant or more abundant than oxygen (Hovestadt et al., SP2.1-13) and that the composition of all heavy nuclei above O was enriched (Hovestadt et al., SP2.1-13; Hurford et al., SP2.1-16).

Ramaty and Kozlovsky (1974) have proposed a thick target, anisotropic emission model which can explain moderately large $^3He/^4He$ ratios and the absence of deuterium and tritium. Stephens and Balasubrahmanyan (SP2.1-17) consider inhomogeneities in the concentration of ^3He in the sun but find large concentrations of ^3He, even on microscopic scales, difficult to maintain. None of the theories proposed to date can explain all the characteristics of ^3He rich events. In particular, they cannot explain the large $^3He/^4He$ ratios frequently observed and the associated emission of heavy nuclei.

Iron-Rich Events. The systematic enhancement of high Z elements in solar particle events is now well established and Fe/O ratios as high as 0.5 are no longer surprising (Crawford et al.,1975). What is new is the degree to which heavy elements are at times enriched (Gloeckler et al.,1975) and that during such emissions a large amount of ^3He is frequently released. Hovestadt et al.(SP2.1-13) find iron to be more abundant than oxygen and large $^3He/^4He$ ratios in three small intensity increases in 1974. None of these three heavy particle events were associated with solar flares or with significant interplanetary disturbances. Hurford et al. (1975, SP2.1-16) also find that in all of the 5 ^{3}He rich events they detected, elements with $Z \geq 6$ were highly overabundant compared to ^{4}He and protons.

In Figure 8 are shown abundances normalized to oxygen for (a) each of the three iron rich events, (b) particles during a typical moderately quiet-time period, and (c) the solar system. The large enrichment of elements heavier than oxygen is unmistakable as is the depletion of elements lighter than oxygen. The Fe/O ratio of 1.8 ± 0.3 for the May 7-13 event is the largest ever observed. The ^{3}He/^{4}He ratio for this event was measured to be 1.06 ± 0.15.

Results reported by Dobrotin et al. (SP2.1-10) indicate that substantial enrichment of iron is not soley confined to low energy particles. They find that on one occasion (Jan 2, 1974) the Fe/O ratio for particles above ∿ 300 MeV/nuc exceeded 0.5 and that the abundance of Si relative to O was about 0.8. No significant increase was observed in the intensities of protons above ∿ 300 MeV or of low energy heavy ions.

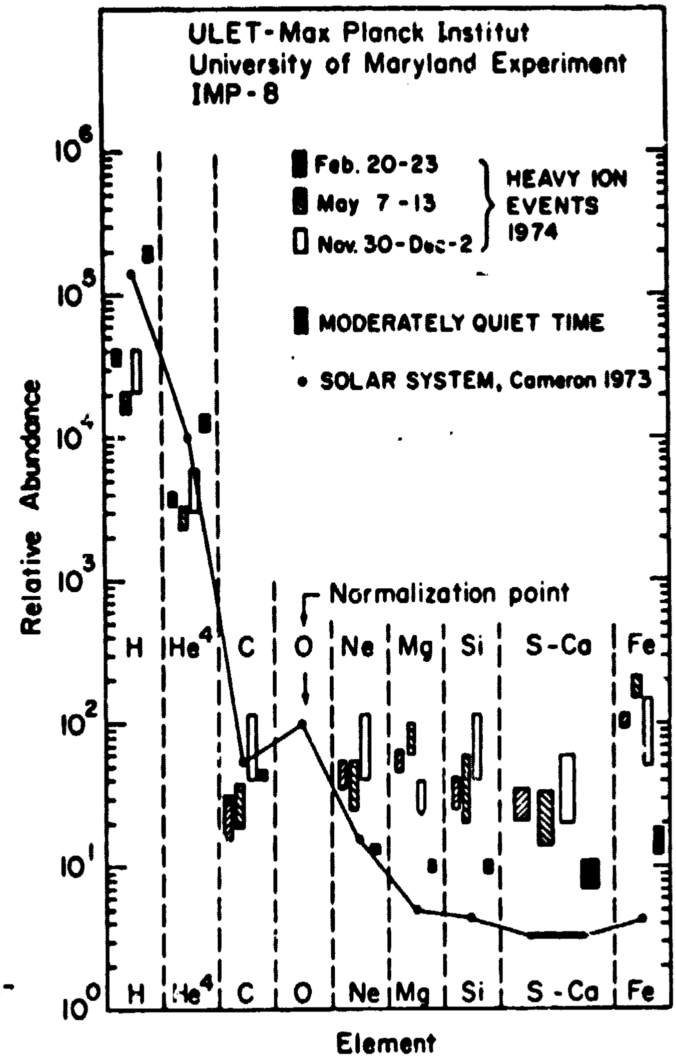

Fig. 8.-Comparison of the relative abundances measured in three "heavy ion events" in 1974 with the sol · system and the moderately quiet-time co ·ition. All abundances are normalized at ox) n. The composition of the 3 "heavy ion events" is strongly enriched in elements heavier than oxygen and depleted in protons, ^{4}He and possibly carbon. All three "events" are ^{3}He rich and in all the abundance of iron is greater than or equal to that of oxygen. (Figure taken from Hovestadt et al., SP2.1-13.)

The various models proposed to account for the enrichment of heavy elements are based either on the fractionation of the elements at the source or on preferrential acceleration and/or escape of heavy ions at the sun. How, at the same time, large amounts of ^{3}He are produced and accelerated remains a puzzle.

7. Nuclear Abundances of Solar Particles. In Table 3 the abundances of solar particles reported at this Conference are compared to the "best" average composition of the solar atmosphere (column 8) and of the solar wind (column 9).

The first reported measurement of the abundances of 1-10 MeV/nuc particles during moderately quiet-times (Hovestadt et al., SP2.1-13; see column 2 of Table 3) indicates a composition enriched in iron and similar to that of the solar wind (Bame, 1972). The composition obtained by von Rosenvinge et al., (SP2.1-3) in the energy range ∿ 10 to 35 MeV/nuc for the sum of all solar particle events from June to October 1974 (column 5) seems to be enriched in Ne, Mg, and Fe when compared with the average abundances of ≥ 10 MeV/nuc solar flare particles (column 7) compiled by Webber (SP2.1-9). To what extent these differences in the composition may be due to a difference in the average size or importance of the flares included in the two respective sets of data is not known at this time.

Table 3. NUCLEAR ABUNDANCES OF SOLAR FLARE PARTICLES

Chemical Element	Moderately Quiet 1974	Fe, He^3 rich 5/7-13/74	Solar Flare 1/24/71	Sum of Flares in 1974	Solar Flare 1/2/74[(a)]	Average Solar Flare	Solar Atmo-sphere	Solar Wind
C	44 ± 3	29 ± 10		51 ± 2.3		49 ± 3	60	
N				15.4 ± 1.2		13 ± 2	14	
O	≡100	≡100	≡100	≡100	≡100	≡100	≡100	≡100
Ne	14 ± 1	40 ± 15	20 ± 4	26.2 ± 1.5		14 ± 2	7-30	10
Na				2 ± 0.3[(b)]		1.9 ± 0.8	0.4	
Mg	10 ± 1	80 ± 20	18 ± 4	29.4 ± 2.2		19 ± 2	8	
Al				3.5 ± 0.5[(b)]		2.4 ± 1	0.6	
Si	10 ± 1	40 ± 20	17 ± 5	14.2 ± 1.9	80 ± 10	14 ± 2	8	21
S-Ca	9 ± 2	24 ± 10				2.5 ± 0.7[(c)]	7	
Fe	16 ± 3	183 ± 30		15.1 ± 1.1	≥50	3-6	3.5	17
He/Fe	815	16				1430	7700	880
Energy Range[(d)]	1-10		3.6-8	∿10-35	≥300	≥10		
Technique	ULET - dE/dx vs E ΔE ≡ proportional counter		Track Detector (CTA)	dE/dx vs E Solid state detectors	Cerenkov	Various		
Paper No. and Authors	SP2.1-13 Hovestadt, Klecker, Vollmer, Gloeckler, Fan		SP2.1-5/6 Durgaprasad, Nevatia, Biswas	SP2.1-3 von Rosenvinge, McDonald, Balasubrahmanyan	SP2.1-10 Dobrotin, Kurnosova, Logachev, Razorenov, Fradkin	SP2.1-9 Compiled by Webber		Bame (1972)

(a) ≤3 protons/(cm^2 sec sr MeV) at ∿ 1 MeV
(b) at ∿ 5 MeV/nuc
(c) Sulfur only
(d) all energy limits in MeV per nucleon

Temporal and Spatial Variations. It was already noted at the Denver Conference (Hovestadt, 1973) that abundance ratios are variable not only from event to event, but also during a particular solar particle event. Therefore, "event averaged" or "snap shot" composition measurements must be interpreted with caution. This view was confirmed in several papers which reported on the variability of abundance ratios (Ipavich et al., SP2.1-2; Gloeckler et al., SP2.1-4; von Rosenvinge et al., SP2.1-3; Armstrong and Krimigis, SP2.1-8). For example, von Rosenvinge et al. (SP2.1-3) find the Fe/O and Mg/O ratios to change by at least a factor of four during the July 3-11, 1974 series of events. For the 9 solar particle events they studied, Gloeckler et al. (SP2.1-4) observe the He/(CNO) ratio to vary from 3 to 28 at low energies (0.02-0.04 MeV/nuc).

Abundance ratios depend also on the position in space where the measurements are made. This point is illustrated in Figure 9 which shows the time dependence of the He/(CNO) ratios measured during a portion of the July 3, 1974 solar particle event by Armstrong and Krimigis (SP2.1-8) using identical detectors on the IMP 7 and IMP 8 spacecraft. Not only are the ratios changing with time, but between 0300 and 0400 UT on July 5 the ratios at IMP 7 are considerably higher than they are on IMP 8.

Looking at really long term time variations, Gopalan and Rao (SP2.1-12) investigated solar particle emission in the early solar system by examining Xe isotope abundances in gas-rich meteorites. They suggest that higher fluxes of solar energetic particles were probably present billions of years ago.

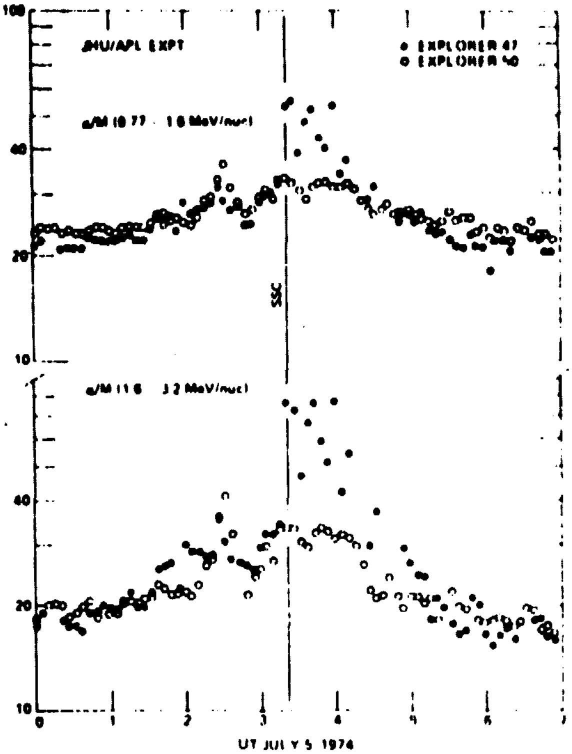

Fig. 9.-Spatial and temporal variations in the He/(Z>3) ratio of solar particles at two energies observed during a seven hour time interval on July 5, 1974. Passage of an interplanetary shock wave is indicated by the vertical line marked SSC. Observations were made using identical detectors on the earth orbiting satellite IMP 7 (Explorer 47) and IMP 8 (Explorer 50) when IMP 8 was located in the upstream interplanetary medium and IMP 7 was passing through the dusk transition region. (Figure taken from Armstrong and Krimigis, SP2.1-8.)

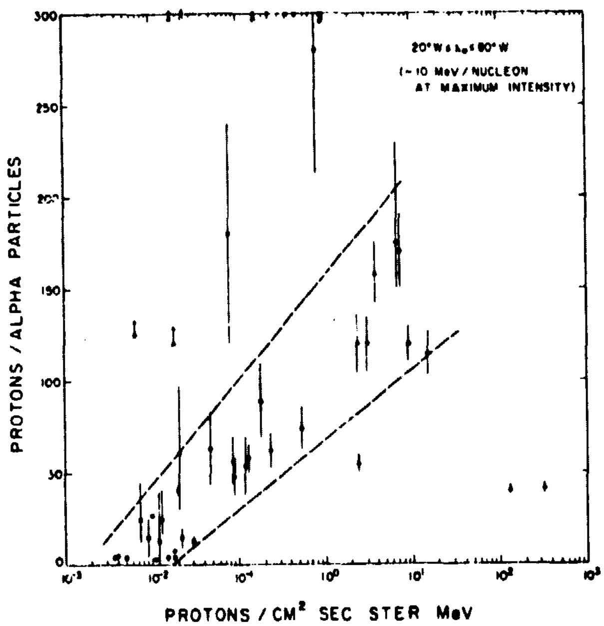

Fig. 10.-Variation of the proton to alpha ratio as a function of the maximum ~10 MeV proton intensity in solar particle events. The region between the two dashed lines includes ~70% of the 45 events. It is evident that the smallest p/α ratios are observed in the least intense solar particle events. (Figure taken from Van Hollebeke, SP2.1-1.)

Statistical Studies. Two papers at this Conference reported results based on statistical studies using a large number of solar particle events. Van Hollebeke (SP2.1-1) analyzed the p/α ratio at ~ 10 MeV/nuc in some 45 solar particle events and finds that this ratio is correlated with the maximum proton intensity of the event as is shown in Figure 10. Small p/α ratios are observed in small intensity or micro events which are generally also enriched in ^{3}He. Furthermore, she finds that the energy spectrum of protons in these micro events is considerably steeper than for the larger events. Gloeckler et al. (SP2.1-4) also find a correlation between the spectral index of low energy CNO nuclei and the "event averaged" proton flux as is evident from Figure 11. In each of the 9 events, they observe a bend-over in the energy spectra of CNO below ∿ 0.2 MeV/nuc which they attribute to energy losses by ionization during storage in the lower corona on the order of several hours followed by substantial adiabatic deceleration in the interplanetary medium. It is clear from data presented in Figure 11 that in the larger events the bend-over is most pronounced, while in small events the spectra remain steep, in agreement with the results of Van Hollebeke (SP2.1-1).

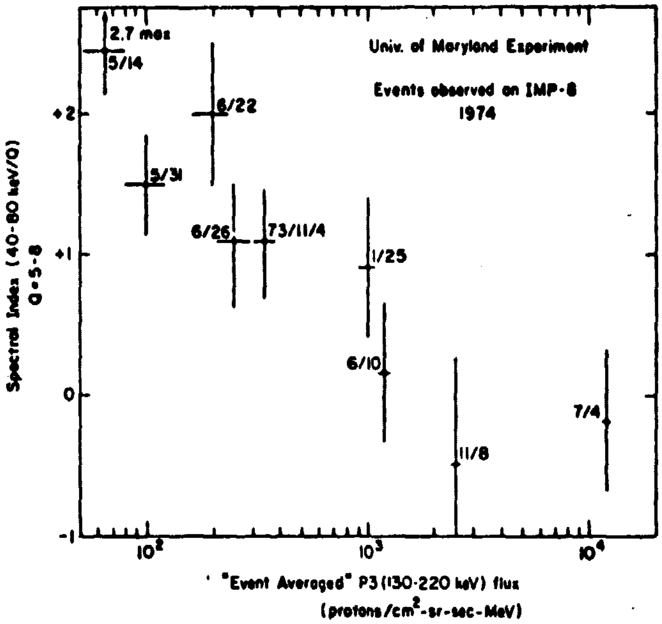

Fig. 11.-Variations in the spectral index of 0.02-0.04 MeV/nuc C+O as a function of the average intensity of 0.13 to 0.22 MeV protons for nine solar particle events. The smallest events are characterized by steep spectra while for the large events the spectrum is flat. These results are interpreted on the basis of energy losses by ionization of particles during storage in the solar corona as discussed in the text. (Figure taken from Gloeckler et al., SP2.1-4.)

Charge States. The state of ionization may well be one aspect of solar particles which does not change. Using an electrostatic deflection analyzer, Gloeckler et al. (SP2.1-4) are able to measure directly the charge states of ions in the energy range of ∿ 0.02 to 0.06 MeV/nuc. They find consistently C and O to be almost fully stripped even at the lowest energies (0.02 MeV/nuc). For example in the July 4, 1974 solar particle event the mean charge states of carbon and oxygen were measured to be 5.5 and 7.2 respectively. These values are similar to those they reported at the Denver Conference for a small solar event (Gloeckler et al., 1973).

8. Nuclear Reaction Products in Flares. A natural consequence of particle acceleration in flares is the generation of secondary particles and photons as a result of nuclear reactions in the solar atmosphere. It is in this area where theoretical work has progressed considerably and where experimental information is most lacking.

Measurements of Nuclear Reaction Products. A summary of measurements of secondary particles produced in nuclear reactions based on work reported at this Conference is given in Table 4. Hurford et al. (SP2.1-16) have extended isotope measurements in flares to new low energy limits and find general agreement between their experimental results and calculation based on a thin-target model of Ramaty and Koslovsky (1974). The upper limit for the e^+/e^- ratio near ∿ 1 MeV for ^3He rich events (Mewaldt et al., SP3-8) was measured to be about the same as the e^+/e^- limit for flares with a normal isotopic composition.

Table 4. NUCLEAR REACTION PRODUCTS IN FLARES

Ratio	Energy Range (MeV/nuc)	Value
$^3H/^1H^{(a)}$	1.2 - 6.8	3.4×10^{-6}
$^2H/^1H^{(a)}$	1.6 - 8.6	$7^{+10}_{-6} \times 10^{-6}$
$^3He/^4He^{(a)}$	∿ 3 - 15	$(9 \pm 4) \times 10^{-3}$
$^3He/^1H^{(a)}$	∿ 3 - 15	$(1.7 \pm 0.7) \times 10^{-4}$
$e^+/e^{-(b)}$	0.16 - 1.6	$\leq 5 \times 10^{-3}$

(a) Hurford, Stone, Vogt (SP2.1-16)

(b) In ^3He rich events, Mewaldt, Stone, Vogt (SP3-8)

Theoretical Investigations on Particle and Photon Production in Flares. Considerable progress has been made on calculating the time profiles for γ-ray lines (Ramaty and Wang, SP3-1; Kanbach et al., SP3-3), neutron, γ-ray, and ^3He production (Baisakalova et al., SP3-2, Ahluwalia, SP3-5; Ibragimov and Kocharov, SP2.1-15), positron annihilation (Crannell et al., SP3-6), and the total number of accelerated particles (Bai and Ramaty, SP3-7; Ibragimov and Kocharov, SP2.1-15) in flare regions. For example, Bai and Ramaty (SP3-7) have deduced for the August 4, 1972 flare the intensity and the spectrum of electrons in the flare region from the observed continuum γ-ray emission and X-ray flux. Because of the complexity of the deduced electron spectrum, which includes a hump above ∿ 0.7 MeV, they conclude that high and low energy electrons are accelerated by different mechanisms. Combining γ-ray and radio data these authors estimate the magnetic field and ambient density in the flare region. They report a p/e^- ratio of ∿100 at ∿10 MeV, a magnetic field strength of ∿ 370 gauss and a density of 6×10^{10} in the flare region. It is a pity that more experimental observations on reaction products are not available since such information is of vital importance in arriving at parameters characterizing the acceleration process.

9. Conclusions. With this brief and admittedly sketchy overview of our current knowledge on low energy particles produced in our solar system I hope to have conveyed, on the one hand, our lack of understanding of a whole variety of puzzling observations and, on the other, a lack of observations in areas which are well understood theoretically. What are the needs and prospects for the future?

(1) For the very low-energy, quiet-time protons and alphas whose origin is not known, measurements must now be extended to study the long term modulation and the evolution of this component with heliocentric distance. Such observations are not easy but are, I believe, possible with instruments on current and planned spacecraft.

(2) The question of origin of the anomalous component will probably not be entirely settled until direct charge state measurements are made or particle acceleration in interplanetary space is demonstrated. Neither of these measurements are easy.

(3) To understand the unexpected observations on particle emissions from the sun will require models and theories to bring some order to the present state of apparent chaos. Experimentally, we need more statistical studies instead of isolated measurements in order to established systematic and

correlative relationships which undoubtedly exist. To achieve these objectives it is vitally important to maintain in operation functioning spacecraft over extended time periods in order to obtain the large sample of events required for analysis. I believe that considerable progress could be made in this area over the next few years.

(4) Finally, to study particle acceleration in the sun or elsewhere in our solar system will require simultaneous and complementary observations of particles and photons over an extended energy and frequency range. Such unified observations are, in general, lacking and in many instances important experimental information is unavailable. Our understanding of these processes will be incomplete unless composition measurements are extended on the one hand to even lower energies, including solar wind particles, and on the other, to the rare elements at higher energies during micro events. Experimental techniques to do all of these measurements exist today. I hope it will be possible to fly these experiments soon.

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