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However it must be emphasized that to date neither NASA nor the Goddard Space Flight Center have any established views on ^3He generated in solar cosmic ray events. If such views do become available, every effort will be made to see that they are distributed to our mailing list.

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Solar Particle Events With Anomolously Large Relative Abundance of ^3He

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Experimental results on three solar energetic particle events with extremely high abundance of ^3He are reported. These events took place during 28-29 May, 1969. The measurements, using the Goddard Cosmic ray telescope on board the OGO-V satellite, cover an energy range of $\sim$ 4 to 80 MeV nucleon^{-1}. In the first of these events $\Gamma(^3He/^4He) = 1.52 \pm 0.1$ (where Γ is the ratio of the two species in an energy per nucleon representation). In the two subsequent events $\Gamma(^3He/^4He)$ had values of 0.71 ± 0.06 and 0.35 ± 0.03, respectively. The abundance of protons relative to He nuclei was significantly low in these events. Not more than four ^2H and three ^3H were detected during the entire period under study compared to 1110 ^3He nuclei. The lower limits of $\Gamma(^3He/^2H)$ obtained for these three events were 300, 250, and 63 respectively, and are much higher than the upper limits expected from theoretical considerations. Results from these events are compared with the data available from other experiments. The limitations these observations place on theoretical models to explain ^3He-rich flares are discussed.

Subject headings: abundances, cosmic rays - flares, solar.

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I. INTRODUCTION

The detection of γ-ray lines from excited nuclei (Chupp et al 1973) and ^2H, ^3H and ^3He produced in interaction with solar energetic particles accelerated during solar flares (Hsieh and Simpson 1970) have pointed to the importance of nuclear reactions in the Solar environment. In comparison with the chromosphere upper limit of (0.01 ± 0.005) for $^3He/^4He$ ratio (Namba, 1965), Hsieh and Simpson found $\Gamma(^3He/^4He) = (2.1 \pm 0.4) \times 10^{-2}$ in the energy range 10-100 MeV/nucleon for the sum of seven flares detected on IMP-4. (Γ represents the ratio of the abundances of the two species in an energy-per-nucleon representation.) For an event on November 2, 1969 Dietrich (1973) and Anglin et al (1973) reported $\Gamma(^3He/^4He) = (7.2 \pm 2.2) \times 10^{-2}$. The value for $\Gamma(^3He/^4He)$ for the November 2, 1969 event exceeds the chromospheric upper limit of Namba by at least a factor of five and the solar wind values by a factor of 100 (Geiss et al 1970, and Geiss et al 1972). This result was interpreted as evidence for the production of ^3He via nuclear reactions by energetic particles in the solar atmosphere as distinguished from the acceleration of the ambient Solar ^3He to high energies. However, in the case of many events it was found (Garrard et al 1973, Anglin et al 1973) that the abundance of ^3He relative to ^2H and ^3H was very large in contrast with expectations from the theory of nuclear reactions (Lingenfelter and Ramaty, 1967).

The major ^3He producing reactions are (p,p) (p,α) and (α,p) interactions (Ramaty and Kozlovsky, 1974). These reactions also produce ^2H and ^3H for energies below 10 MeV nucleon^{-1} isotope production is entirely due to the (p,α) reactions. Above 20 MeV nucleon^{-1} (α,p) reactions make a major contribution to the production of ^3H and ^3He. For ^3H, (p,α)

reactions are important in this energy region also. Ramaty and Kozlovsky (1974) have developed theoretical models where they have taken into account effects of kinematics of the reactions and the possible anisotropy of solar beams. They find that for energetic protons and ^{4}He nuclei impinging on the solar atmosphere ^{3}He could be preferentially emitted in a direction opposite to that of the incident particle while the isotopes of H would tend to have the same direction.

In this paper we are presenting energetic particle data from a series of solar flares which took place during 28-29 May 1969 and were associated with McMath plage region 10109. In the first of these flares, $\Gamma[^1H/$

$\Gamma(^3He/^4He)$ = 1.52 $\pm$ 0.10 in the energy range 4-80 MeV nucleon^{-1}.

$(^3He + ^4He)]$ was 1.00 $\pm$ .05.

In the

subsequent events $\Gamma(^3He/^4He)$ decreased to 0.71 $\pm$ .06 and 0.35 $\pm$ .03, respectively. The first two events have a relative abundance of ^{3}He much higher than that of any events reported so far. Due to the high data rate of the experiment the total number of ^{3}He nuclei detected over all these events was 1110 (larger by more than a factor of 10 than any other reported measurements). It is interesting to note that all these events with large $\Gamma(^3He/^4He)$ are small solar particle events with peak proton fluxes < 0.1 particles cm^{-2} ster^{-1} sec^{-1}. It is possible that this type of events go undetected because of their small size unfavorable interplanetary magnetic field configuration the low bit rate and small geometry factors of telescopes studying solar particle events.

We present experimental data from these extraordinary events and discuss the limitations these observations place on theoretical models of ^{3}He-rich events. Preliminary accounts of the observations were given by Serlemitsos and Balasubrahmanyan (1974), and Balasubrahmanyan and Serlemitsos (1974).

II. Description of the Experiment

a) Detectors

The measurements were made with the Goddard Cosmic Ray experiment on board the OGO-V Satellite (Jones et al, 1967; Teegarden, McDonald, and Balasubrahmanyan 1970). The experiment consists of a set of three cosmic ray telescopes designed to cover a wide energy range of the particles under study. A schematic diagram of these telescopes is shown in Figure 1. The low, medium, and high energy telescopes are referred to as L.E.D., M.E.D. and H.E.D., respectively.

The Low Energy Detector is a solid state dE/dx vs E telescope, consisting of semi-conductor detectors G, and H surrounded by a plastic scintillator anti-coincidence shield (J). G is a thin silicon surface barrier detector (150 microns) for measuring the dE/dx of the incident particles. H consists of two, 1-mm thick silicon detectors, whose signals are added together. It measures the residual energy of particles stopping in the L.E.D. telescope. In Table 1 the energy ranges of the L.E.D. telescope for the isotopes of H and He are given.

The mass resolution of the telescopes was more than adequate to identify the isotopes of H and He (Figure 2 and 3). The two dimensional array for the May 28 event is given in Figure 2. ^{2}H and ^{3}H nuclei could be identified because of the low background of the system.

TABLE 1

Energy response of L.E.D.

Particle	Energy range (MeV $nucleon^{-1}$)
^{1}H	4-19
^{2}H	2.7-13
^{3}H	2.1-10
^{3}He	4.6-23
^{4}He	4-19

The Medium Energy Detector consists of three CsI scintillators (D,E,V) which form a dE/dx vs E telescope. A cylindrical plastic scintillator E helps to select stopping particles and reduces the background produced by nuclear interactions. For stopping protons and ^{4}He nuclei, the energy range of the M.E.D. is 20-80 MeV $nucleon^{-1}$.

The High Energy Detector consists of two identical CsI scintillators (A and B), each 1 g/cm^2 thick, and a sapphire Cerenkov counter (C) 1 cm thick. For the study of solar flare particles, the double scintillator telescope consisting of A and B was used. This double scintillator telescope acts as a dE/dx vs E telescope for particles stopping in B. These three telescopes complement each other and provide reliable measurements from 4-80 MeV $nucleon^{-1}$ for these events. Beyond 80 MeV $nucleon^{-1}$ the mass resolution of the detectors decreased rapidly.

The energy threshold for the detector A (H.E.D.) was set at 300 keV. The threshold for detector D (M.E.D.) was 1 MeV. Both these CsI scintillators were able to detect low energy electrons and γ-rays. By a comparison of the increases of counts in detectors A and D it is possible to study the time history of electrons from solar flares.

III(a). Data Analysis --(General)

The analysis in this study is restricted to particles below 80 MeV nucleon^{-1} (i.e. particles which stop in one of the three detector arrays). The analysis is a two dimensional correlation of the energy loss in a thin detector with the residual energy in the thick detector where the indicent particle comes to rest.

The maximum energy of a stopping particle can be calculated theoretically from range-energy relations (Barkas and Berger 1964). This theoretically calculated maximum energy is associated with the end point seen in the two dimensional pulse height distribution. Response curves are constructed for each isotope, using range-energy relations.

Corrections have to be made to the raw data for

a) non-linearities in P.H.A. response

b) non-linearities in the response of the CsI scintillator due to variation of light output with energy deposited by ionization loss of incident particles.

c) gain shift of the system with time.

The corrections for P.H.A. non-linearities were obtained from laboratory calibration. Corrections for the non-linearity of the scintillators were obtained by accelerator calibrations with protons and He nuclei at different energies. The Gainshift of the system is essentially due to temperature variations. The gainshift of the electronics system was small (maximum amplitude ~ 5%) compared to the gainshift of CsI-Photomultiplier combinations.

III(b). He-isotope Analysis

Calculated response curves of doubly charged particles with masses varying from 2 to 5 a.m.u. at intervals of 0.1 a.m.u. were constructed. Histograms obtained by counting the number of nuclei falling within these 0.1 a.m.u. intervals are shown in Figure 3 for solar events on 2nd of November, 1969 and 28th May 1969. For the November event we estimate $\Gamma(^3He/^4He) \sim 8 \times 10^{-2}$ in good agreement with the value $(7.7 \pm 2.0) \times 10^{-2}$ reported for the same event by Dietrich (1973). As can be seen from Figures 2 and 3, the ^3He and ^4He are well resolved.

The number of ^2H nuclei detected was 4 for the entire period under study. The corresponding number for ^3H was 3. The general cleanliness of the matrix in the ^2H and ^3H regions gives confidence on the validity of these upper limits for isotopes of H.

IV. Results

Some of the relevant parameters associated with the solar flares reported in this paper are listed in Table 2. Five solar flares were observed during the period under study. Each of these was associated with solar X-ray and radio emissions. Particle increases were seen for four of these flares. The flare at 1440 on the 29th May was not associated with any detectable increase in particle intensity as seen by our detector. The second and third flares occur with a separation only of ~ 2 hours and so the statistical accuracy of the data does not warrant their treatment as separate events. For the purpose of this paper, we have combined data from these two flares and treated them as one event.

TABLE 2

FLARE DATA

FLARE NO.	TIME	COORDINATES	McMATH PLAGE REGION	IMPORTANCE	X-RAY EMISSION	RADIO EMISSION	REMARKS
1	5/28/69 1248	W59 N10	10109	1B–(2B)	YES	TYPE III TYPE II TYPE IV	$^3He/^4He \sim 1.5$
2	5/29/69 0020	W64 N11	10109	1B	YES	TYPE I TYPE III	$^3He/^4He \sim 0.7$
3	0405	W66 N12	10109	1B(–1N)	YES	TYPE II TYPE III	
4	1440	W73 N11	10109	1B	YES	TYPE II	NO PARTICLES
5	1939	W76 N12	10109	1B	YES	TYPE III	$^3He/^4He \sim 0.35$ LARGE ELECTRON FLUX

From Solar Geophysical Data

All these flares are associated with the McMath plage region 10109. The first flare started at 12:48 on May 28. Particle increase was detected approximately two hours after the optical flare. This event was very rich in ^{3}He with ~ 560 particles detected in a 12 hour period. In the following two events the number of ^{3}He particles detected were 250 and 300 respectively.

In Figure 4 the time histories of ^{1}H, ^{3}He and ^{4}He are shown for the entire period under study. In the same figure the ratio of the counting rates of A and D detectors, (A/D), which is a measure of the electron intensity is also shown. For the first event no electron on-set data is available as the event started when the satellite was close to perigee. In Figure 5 the counting rate of the A scintillator is shown. Sharp increases in the counting rates of A in the three observed cases are consistent with the propagation delay applicable to electrons for a scatter-free propagation along the Archimedes Spiral pattern of the interplanetary magnetic field.

In Figure 6 the energy distributions of ^{1}H, ^{3}He, and ^{4}He averaged over the whole of the first event are shown. The energy spectra of all the events are consistent with being power laws in kinetic energy over the complete 4-80 MeV nucleon^{-1} interval. Table 3 gives the values of the spectral exponents (γ) of the energy distribution for the different events. Figure 7 shows the variation of $\Gamma(^3\text{He}/^4\text{He})$ and $\Gamma(^1\text{H}/^4\text{He})$ for the period under study.

TABLE 3

Flare No.	γ		
	Protons	^4He	^3He
1	4.29 ± 0.10	4.16 ± 0.10	4.04 ± 0.11
2 & 3	3.45 ± 0.06	3.55 ± 0.12	3.69 ± 0.12
5	3.99 ± 0.05	3.24 ± 0.05	3.24 ± 0.10

V. Discussion

Hsieh and Simpson (1970) reported a $\Gamma(^3He/^4He) = (2.1 \pm 0.4) \times 10^{-2}$ in energy range 10-100 MeV $nucleon^{-1}$, for the sum for seven flares in early work on this subject. This result was close to the upper limit of .01 for the ambient solar chromospheric abundance ratios of these isotopes (Namba, 1965).

In later work, Anglin, Dietrich and Simpson (1973a,b) and Dietrich (1973) conclude that the ratio of $^3He/^4He$ from some events was more than an order of magnitude above solar atmospheric abundances. Garrard, Stone, and vogt (1973) report $\Gamma(^3He/^4He) = 0.26 \pm 0.08$ for the event on October 14, 1968. Anglin, Dietrich and Simpson (1973b) summarize their results by classifying their IMP 5 and 6 data into two types of flares:

a) ^3He-rich with $\Gamma(^3He/^4He) \geqslant 3.3 \times 10^{-3}$

b) He^3-poor with $\Gamma(^3He/^4He) \leqslant 1.5 \times 10^{-2}$

It is, however, quite possible that $\Gamma(^3He/^4He)$ has a continuous distribution in values.

The results for events with $\Gamma(^3He/^4He) > 0.2$ observed by us are shown in Table 4. Results from other experimenters when available are also included in the table. From the Table 4 it may be seen that $\Gamma(^3He/^4He)$ is highly variable from event to event. Furthermore, all are associated with relatively small particle events. The peak integral intensity of protons of energy > 10 MeV for these events is in the range of 10^{-2} - 10^{-1} particles/cm ster. sec.

For the events reported in this paper, the values $\Gamma(^3He/^4He)$ are 1.52 ± 0.1, $0.71 \pm .06$ and 0.35 ± 0.03. It may be significant that all these flares are from the same McMath region 10109. The events have very low abundance of ^2H and ^3H. The summarized results of Anglin, Dietrich and Simpson (1973a) from their IMP 5 and 6 data give $\Gamma(^2H/^4He) = (1.1 \pm 0.2) \times 10^{-2}$ for the ^3He rich flares. The relative abundance ^2H compared to ^3He is very small for the event on 14th October 1969. From the low $\Gamma(^2H/^3He)$ Garrard et al. conclude that the event does not seem to be consistent with the existing calculations of the nuclear reaction origin of these isotopes (Lingenfelter and Ramaty, 1967).

Ramaty and Kozlovsky (1974) have proposed a theory dealing with several features of nuclear reactions in solar flares. They use updated cross-sections and extend their calculations to very low energies (~0.1 MeV nucleon^{-1}). The effects of angular distribution of the secondary products have an important effect and are taken into account in their theory. In the 2 body reaction $p + \alpha \rightarrow {}^2H + {}^3He$, for example, ^2H is emitted in the direction of the incident high energy proton whereas ^3He is emitted in

TABLE 4

Date	4.6 - 19 MeV/n	4 - 19 MeV/n	One Sigma Upper Limits		Remarks
	$\Gamma(^3He/^4He)$	$\Gamma[^1H_1/(^4He+^3He)$	$\Gamma(^2H_1/^3He)$	$\Gamma(^3H_1/^3He)$	
May 5, 1969	0.53 ± 0.07	17.0 ± 1.0	$< 4.0 \times 10^{-2}$	$< 4.0 \times 10^{-2}$	$2-^2H_1$; $2-^3H_1$; $103-^3He$
May 28, 1969	1.52 ± 0.1	1.00 ± 0.05	$< 3.6 \times 10^{-3}$	$< 1.8 \times 10^{-3}$	$1-^2H_1$; $0-^3H_1$; $560-^3He$
May 29, 1969(A)	0.71 ± 0.06	4.03 ± 0.18	$< 4.0 \times 10^{-3}$	$< 8.0 \times 10^{-3}$	$0-^2H_1$; $1-^3H_1$; $250-^3He$
May 29, 1969(B)	0.35 ± 0.03	2.69 ± 0.10	$< 1.6 \times 10^{-2}$	$< 1.1 \times 10^{-2}$	$3-^2H_1$; $2-^3H_1$; $300-^3He$
October 14, 1969	0.45 ± 0.06*	50.6 ± 2.9	$< 5.5 \times 10^{-2}$	$< 2.3 \times 10^{-2}$	$3-^2H_1$; $1-^3H_1$; $86-^3He$
July 30, 1970	0.45 ± 0.06**	4.4 ± 0.3	$< 1.1 \times 10^{-2}$	$< 5.3 \times 10^{-2}$	$0-^2H_1$; $3-^3H_1$; $89-^3He$

* Value Reported by Garrard et al (1973) $\Gamma(^3He/^4He)$ = 0.26 for 4 - 5 MeV/nucleon

** Value Reported by Anglin et al (1974) $\Gamma(^3He/^4He)$ = 0.54 for 10 - 50 MeV/nucleon the backward direction. For the 3 body reactions the available experimental data is less complete. But Ramaty and Kozlovsky have used available data and taken the effects of angular distributions for the detection of the different isotopes of H and He. They have considered two models--a thick target model and a thin target model. Their calculations show that for the case when solar energetic particle beams are directed towards the solar photosphere, it is possible to have large $\Gamma(^{3}He/^{2}H, ^{3}H)$ because of the anisotropic emission of the isotopes of ^{3}He, ^{3}H and ^{2}H.

They apply their calculation to the giant flare on August 4, 1972. For this event both ^{3}He (Webber et al. 1973) and γ-rays (Chupp et al. 1973) were observed. Ramaty and Kozlovsky find that in order to account for even the very low $\Gamma(^{3}He/^{4}He)$ in the August event (~2%) the incident particles must have travelled through $\sim$ 2 g/cm^2. However, very large parth lengths would be required for the three events reported here - $\sim$ 170, 80 and 33 g/cm^2, respectively. Furthermore, to balance ionization energy loss, continuous acceleration has to be postulated with several GeV of energy being supplied to each Helium nucleus. This should also greatly alter the charge composition at higher Z. Since there was no priority event selection on this experiment, it was not possible to extend this study to $Z \geqq 3$.

Another puzzling feature detected in the May 1969 flares is the low abundance of protons compared to He nuclei. In this respect, events reported in this paper differ considerably from the November 2, 1969 and

January 25, 1971 events studied by Dietrich (1973), and other events in Table 4 except for July 30, 1970. For our events $\Gamma[^1H/(^3He+^4He)]$ = 1.00 ± 0.05, 4.03 ± 0.18 and 2.69 ± 0.10, respectively. The corresponding $\Gamma(^1H/^4He)]$ = 2.52 ± 0.12, 6.74 ± 0.31, and 4.02 ± 0.14, respectively. These ratios are small compared to the average value $\Gamma(^1H/^4He) \sim 100$ at the same energy obtained by Hsieh and Simpson, 1970.

The very low abundances of ^2H and ^3H suggests that a selection process such as that proposed by Ramaty and Kozlovsky might be operating on a flux of particles that are predominantly directed toward the sun with only a few percent escaping. Somewhat similar processes have already been identified for solar electrons. Holt and Ramaty (1969) and Lin (1974) using solar X-ray and electron data have established that only ~ 0.10% of the electrons escape from the Sun.

Since most of the ^3He produced have energies in the range .1 to 1 MeV/nucleon, some type of post-acceleration is clearly necessary to account for the constancy of the ratio over the 4-80 MeV/Nuc interval. Large fluxes of nuclear gamma-rays should be generated in these events. The time scale of the production processes of the isotopes would be defined by the duration of the γ-ray emission.

However, the lower limits obtained experimentally for $\Gamma(^3He/^2H)$ are more than a factor of 15 larger than the upper limit predicted by Ramaty and Kozlovsky. Also puzzling is the similarity of the spectra observed for ^1H, ^3He and ^4He. Clearly further refinements to the Ramaty-Kozlovsky model are necessary. It is also possible that some entirely new mechanism is producing the observed ^3He enhancement.

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FIGURE CAPTIONS

1. Schematic diagram of the particle detectors on OGO-V.

2. Two dimensional distribution of the pulse heights in detector G vs the pulse heights in H. The continuous curves for ^{1}H, ^{2}H, ^{3}H, ^{3}He and ^{4}He are calculated response curves. Also shown are the expected response curves for pile up for two protons and three protons. The tail of the distribution has negligible contributions in the ^{2}H and ^{3}He regions.

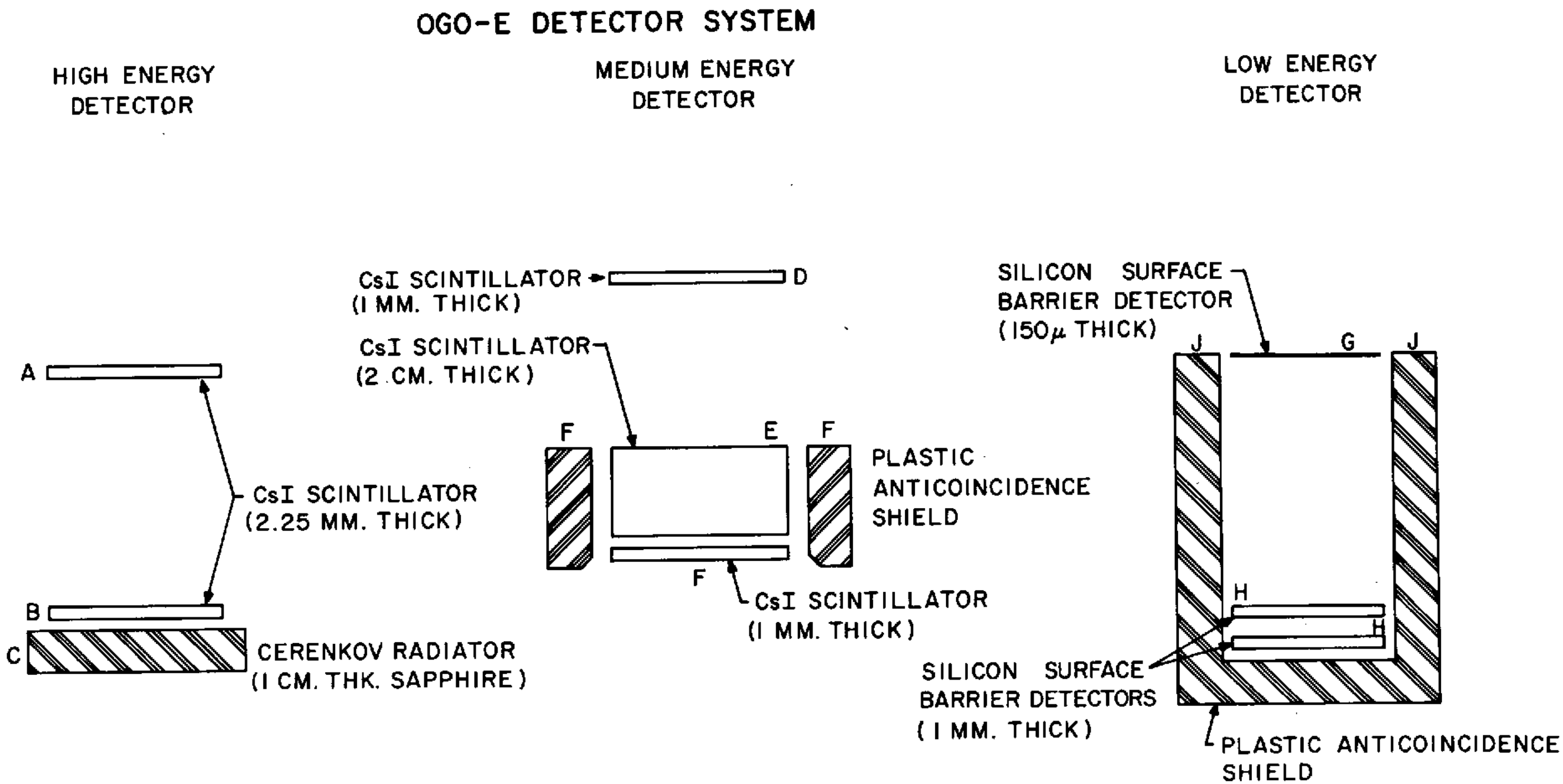
3. Helium mass histogram for ^{3}He-rich events on 28 May 1969 and 2 November 1969. Note dominance of ^{3}He peak for the May event. For the November event $\Gamma(^{3}He/^{4}He)$ was 0.08 in good agreement with the results of Dietrich (1973).

4. Time history of ^{1}H, ^{3}He and ^{4}He during the period under study. A/D ratio represents the time history of solar electrons with energy > 300 keV. The sharp rise times of these events indicate scatter free propogation. The on-set time of the events for ^{1}H and He nuclei are consistent with delay times for scatter free propogation along the 8 spiral interplanetary field. It is possible that favorable interplanetary conditions could be an important factor for successful detection of these small events. Note change of scale for ^{3}He.

5. Counting rate of scintillator A. The sharp increases and delay times with respect to the optical flares associated with these events suggest that the increases are due to electrons of energy > 300 keV, propagating in a scatter free mode.

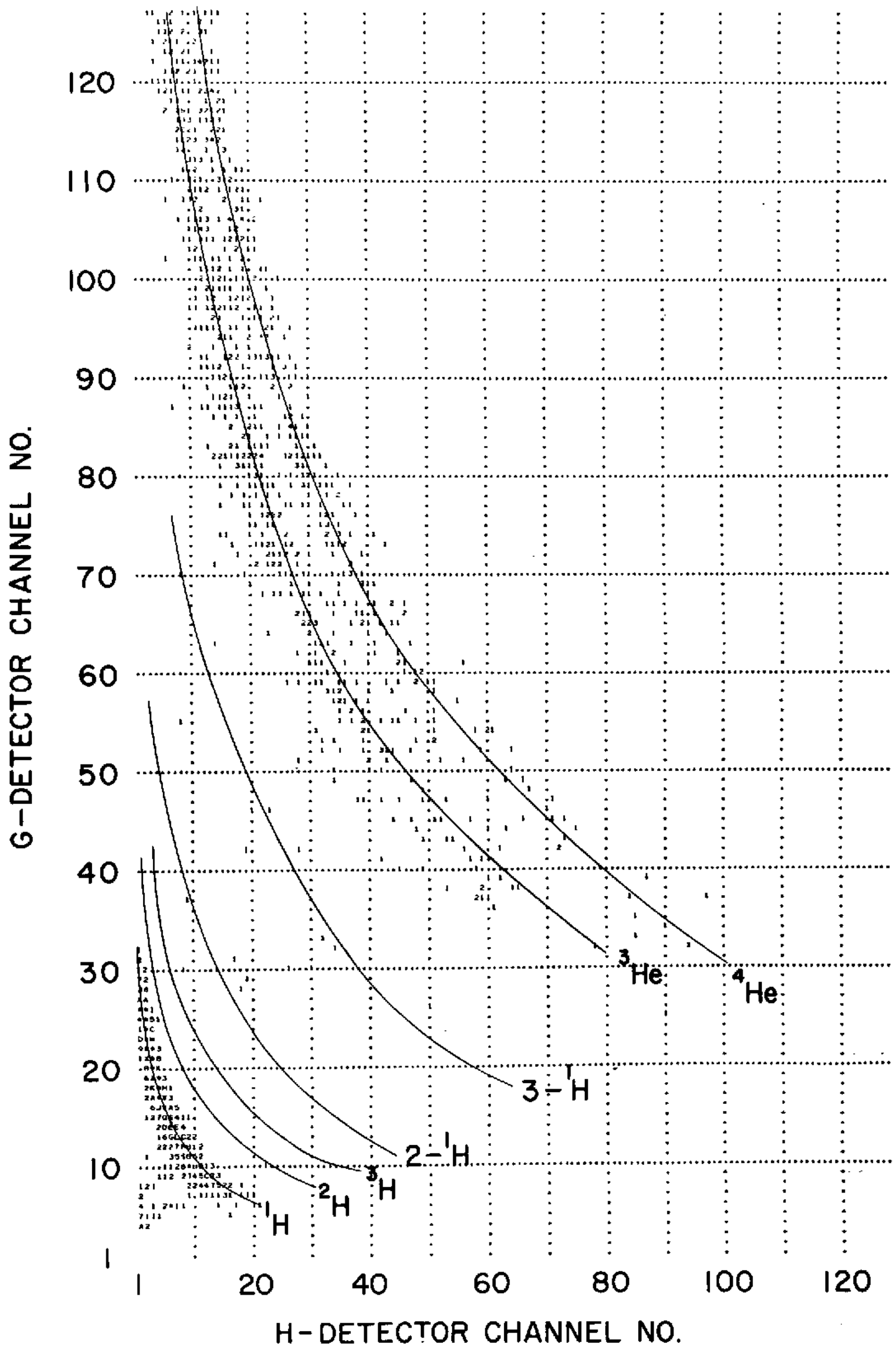
6. Energy spectra of protons, ^{3}He and ^{4}He nuclei for the event of 28th May 1969.

7. Time history of $\Gamma(^{1}H/^{4}He)$ and $\Gamma(^{3}He/^{4}He)$.



OGO-E DETECTOR SYSTEM
HIGH ENERGY DETECTOR
MEDIUM ENERGY DETECTOR
LOW ENERGY DETECTOR
A
B
C
CsI SCINTILLATOR (2.25 MM. THICK)
CERENKOV RADIATOR (1 CM. THK. SAPPHIRE)
CsI SCINTILLATOR (1 MM. THICK)
D
CsI SCINTILLATOR (2 CM. THICK)
F
E
F
PLASTIC ANTICOINCIDENCE SHIELD
F
CsI SCINTILLATOR (1 MM. THICK)
SILICON SURFACE BARRIER DETECTOR (150μ THICK)
J
G
J
H
H
SILICON SURFACE BARRIER DETECTORS (1 MM. THICK)
PLASTIC ANTICOINCIDENCE SHIELD

FIGURE 1



G-DETECTOR CHANNEL NO.
H-DETECTOR CHANNEL NO.
120
110
100
90
80
70
60
50
40
30
20
10
1
20
40
60
80
100
120
³He
⁴He
3-¹H
2-¹H
³H
²H
¹H

FIGURE 2

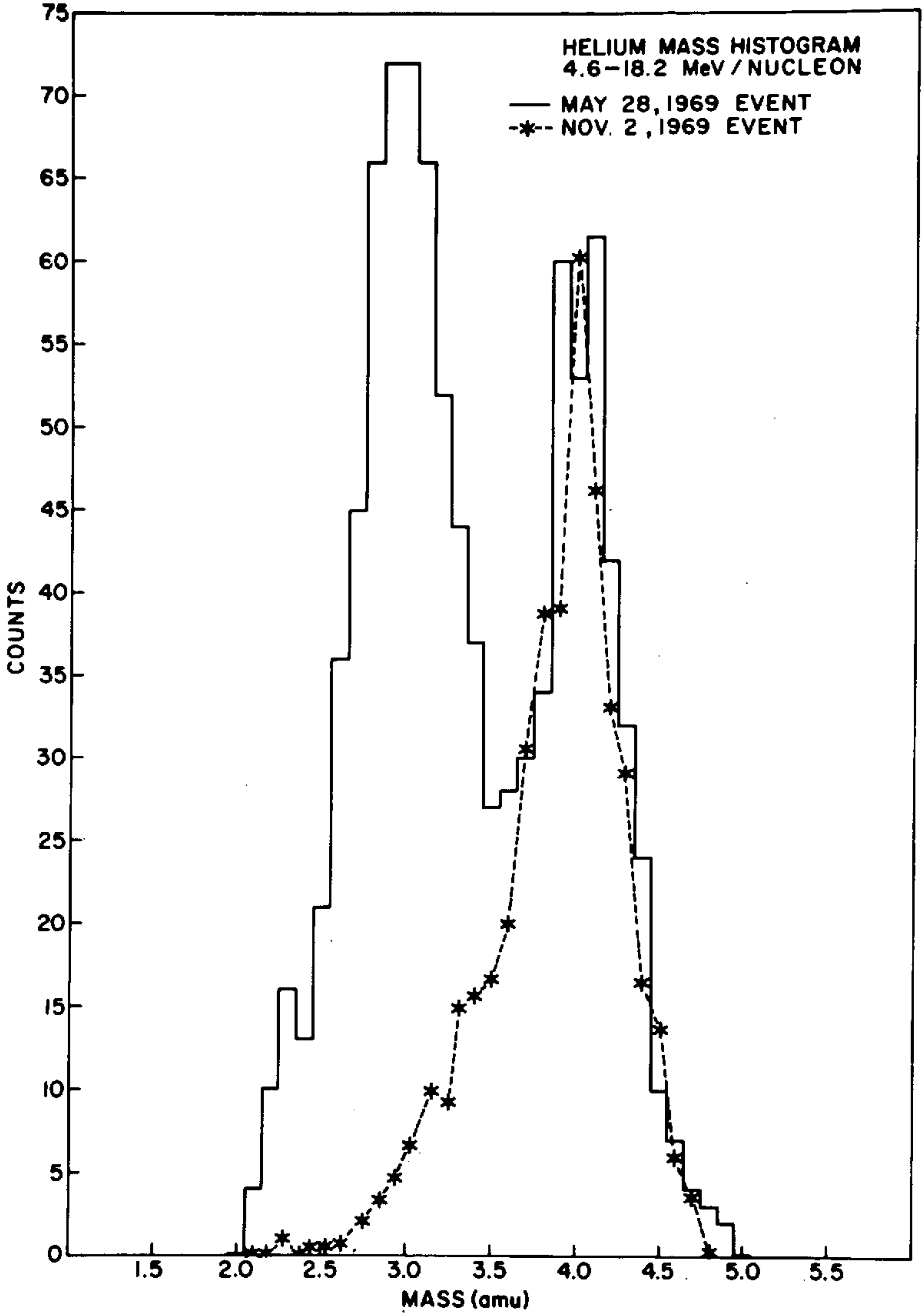
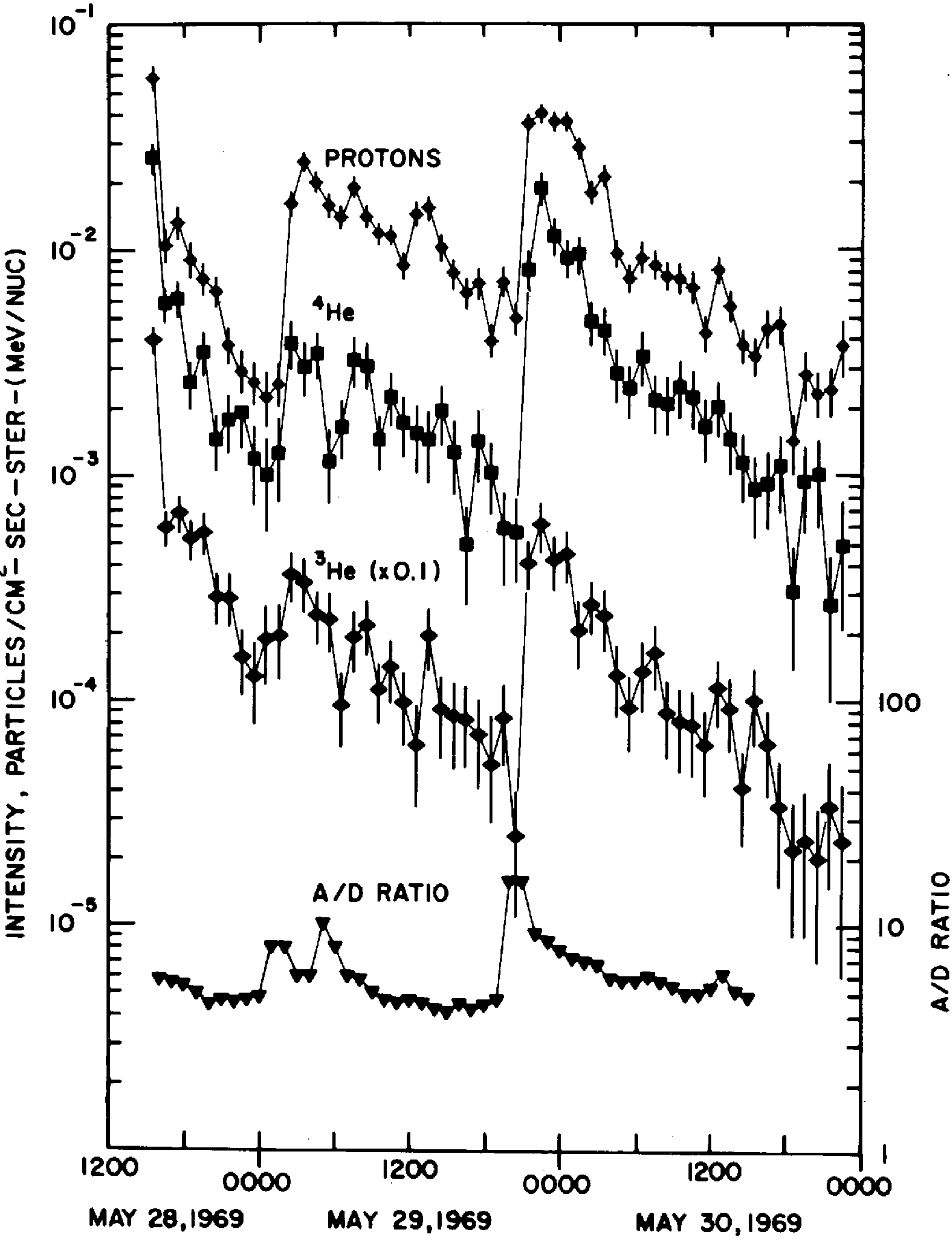
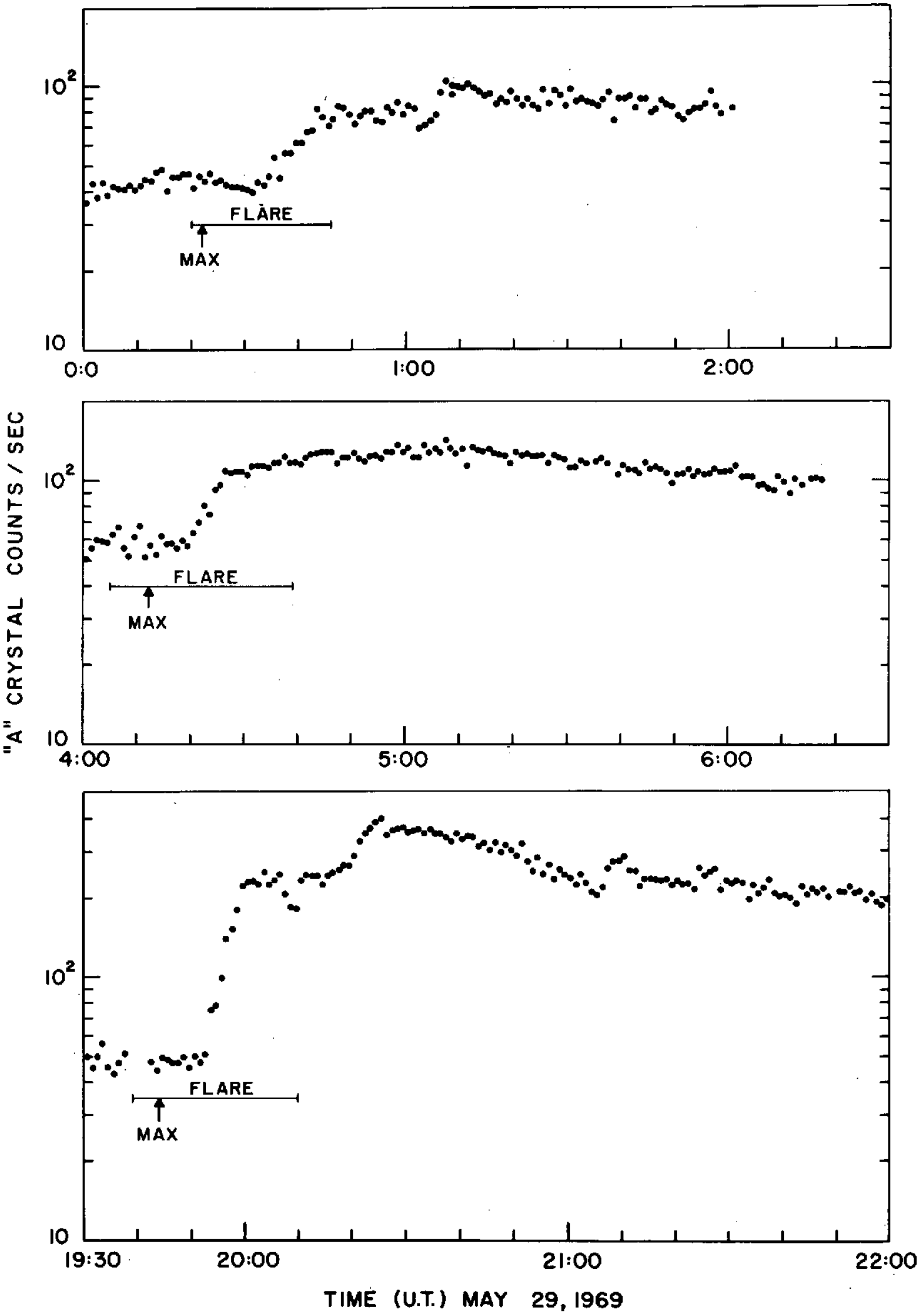

HELIUM MASS HISTOGRAM
4.6-18.2 MeV / NUCLEON
MAY 28, 1969 EVENT
NOV. 2, 1969 EVENT
COUNTS
MASS (amu)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5

FIGURE 3



INTENSITY, PARTICLES/CM^2-SEC-STER-(MeV/NUC)
PROTONS
^{4}He
^{3}He (x0.1)
A/D RATIO
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
100
10
1
1200
0000
1200
0000
1200
0000
MAY 28,1969
MAY 29,1969
MAY 30,1969

FIGURE 4



10²
10
FLARE
MAX
0:0
1:00
2:00
"A" CRYSTAL COUNTS / SEC
10²
10
FLARE
MAX
4:00
5:00
6:00
10²
10
FLARE
MAX
19:30
20:00
21:00
22:00
TIME (U.T.) MAY 29, 1969

FIGURE 5

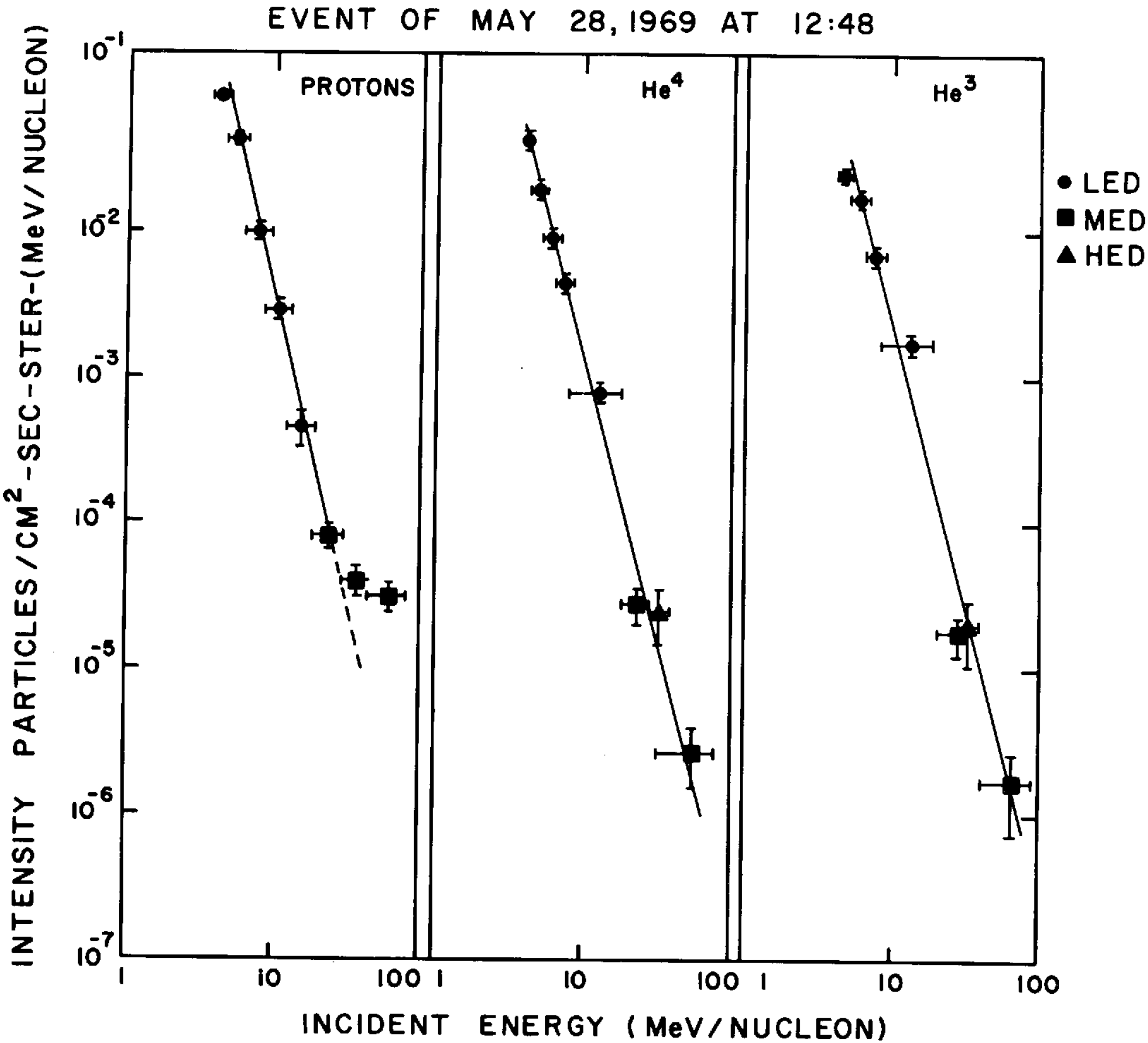

EVENT OF MAY 28, 1969 AT 12:48
PROTONS
He4
He3
LED
MED
HED
INTENSITY PARTICLES/CM2-SEC-STER-(MeV/NUCLEON)
INCIDENT ENERGY (MeV/NUCLEON)
10-1
10-2
10-3
10-4
10-5
10-6
10-7
1
10
100

FIGURE 6

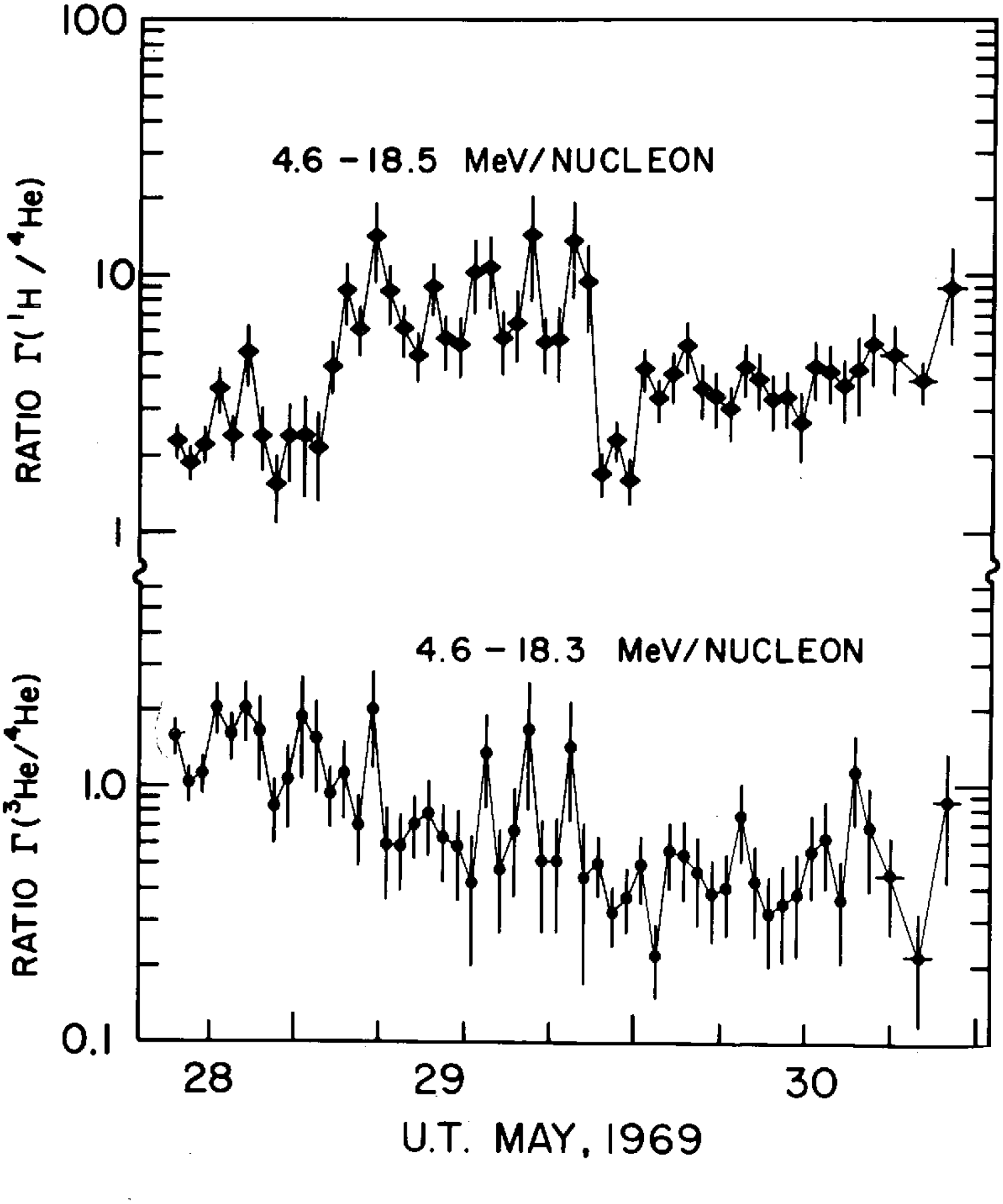

100
10
1
1.0
0.1
4.6 - 18.5 MeV/NUCLEON
4.6 - 18.3 MeV/NUCLEON
RATIO Γ(¹H / ⁴He)
RATIO Γ(³He/⁴He)
28
29
30
U.T. MAY, 1969

FIGURE 7