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A search for ^{3}He enhancements in SEP and CIR-associated events with Ulysses/HI-SCALE

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Abstract. We identify 17 solar energetic particle (SEP) events with enhanced abundances of ^{3}He relative to ^{4}He detected by the Heliosphere Instrument for Spectra, Composition, and Anisotropy at Low Energies (HI-SCALE) on the Ulysses spacecraft. These events were all detected while Ulysses was within 5° of the ecliptic plane, but at distances from the Sun of 1-5 AU. We compare these results to those obtained with the ONR-604 instrument on the Combined Release and Radiation Effects Satellite (CRRES) mission (Chen et al. 1995). Chen et al. found 13 events with enhancements of ^{3}He above normal solar abundances at energies >50 MeV/nucleon. The HI-SCALE instrument measures He ions with energies between 0.3 and 3.1 MeV/nucleon. We identify flux increases in the HI-SCALE data which correspond to 6 of the CRRES events, but we find an enhancement in ^{3}He in only one of these events. We believe this single coincident detection to be a chance occurrence. We use these results, together with the multitude of previous results at different energies, to discuss the overall picture of ^{3}He-rich events as a function of energy. We also analyze the data for ^{3}He enhancements in high latitude co-rotating interaction region (CIR)-associated events observed while the spacecraft was in the southern solar hemisphere above the streamer belt. We find, within the sensitivity of the HI-SCALE instrument, that there is no ^{3}He enhancement in these CIR-associated events. We then briefly discuss how this relates to particle acceleration mechanisms in solar flares.

Key words: Sun: abundances – Sun: flares – Sun: particle emission

1. Introduction

1.1. SEP events

The ambient relative solar abundance of ^{3}He to ^{4}He has been shown to be on the order of a few times 10^{-4} in the solar wind (Bame et al. 1968; Geiss et al. 1970, 1972; Bühler et al. 1971) and in solar prominences (Hall 1975). By studying particles trapped in pieces of the Discoverer 17 satellite, which was flown during an intense solar flare, a ratio of ^{3}He/^{4}He ($\Gamma(^3\mathrm{He}/^4\mathrm{He})$) of 0.2 at about 70 MeV/nucleon was found (Schaeffer & Zähringer 1962). Subsequent observations found that $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ is enhanced in 'impulsive' solar flares for He ions with energies from 0.4 - 100 MeV/nucleon (e.g. Hsieh and Simpson 1970; Hovestadt et al. 1975; Hurford et al. 1975; Möbius et al. 1980). Energetic particles of 'gradual' or 'proton' flares are dominated by protons and have normal solar abundances of the heavier elements (e.g. Meyer 1985a, 1985b; Breneman & Stone 1985; Stone 1989; Reames 1992).

For reviews of observations of ^{3}He-rich events see Ramaty et al. (1980) and Kocharov & Kocharov (1984). In particular, Kocharov & Kocharov spell out the basic characteristics of ^{3}He-rich events: (1) a high $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ abundance ratio reaching values up to about 8; (2) the absence of detectable fluxes of the ^{2}H and ^{3}H isotopes; (3) the proton-to-helium flux ratio is relatively low; (4) at low energies the solar cosmic ray fluxes are enriched in heavy ions; (5) the ^{3}He-rich events are usually associated with weak optical flares and accompanied by X-ray and radio emission. In addition, it has been shown that ^{3}He-rich events are associated with electron events and with type III radio bursts (Reames et al. 1985.) Also, $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ is inversely correlated with event peak rate (Ramaty et al. 1980; Reames et al. 1988).

Using data from the Ultralow-Energy Particle Telescope on IMP 8, it has also been shown that $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ decreases with decreasing energy, in the energy interval between 0.44 and 4.1 MeV/nucleon (Möbius et al. 1980). Möbius et al. found the ratio decreased very rapidly below about 1 MeV/nucleon. However, in one of the six events considered, there was a maximum in the ratio at about 1 MeV/nucleon, with a rapid drop in the ratio at higher energies. For another event, a study of the temporal evolution of $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ found that the ratio increased rapidly at the onset of the particle event, reached a peak before the particle flux, and then decayed considerably faster than the particle flux.

In a later paper, Möbius et al. (1982) combined the IMP 8 data with ISEE 1 and ISEE 3 data, to cover the energy range from 0.4-20 MeV/nucleon. This showed that $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ decreased at higher energies, above about 6 MeV/nucleon. Above about 10 MeV/nucleon, $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ was between 1 and 2 orders of magnitude lower than the peak ratio amplitude. A flare observed with the cosmic-ray experiment on the HELIOS-1 spacecraft had also shown that the $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ decreased with increasing energy in this energy range (Green et al. 1975). Green et al. (1975) found a $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ of about 4.3 at 5 MeV/nucleon which decreased to a $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ of about 1.0 at 11 MeV/nucleon.

While Green et al. (1975) and Möbius et al. (1982) found that $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ appears to be greatest at a few MeV/nucleon, there have been many observations at higher energies which suggest that $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ increases with energy in the range 10 - 110 MeV/nucleon (Hsieh & Simpson 1970; Dietrich 1973; Chen et al. 1995). There are, however, also observations which indicate that $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ is approximately constant from 4 - 80 MeV/nucleon (Balasubrahmanyan & Serlemitsos 1974; Serlemitsos & Balasubrahmanyan 1975; Anglin 1975).

This discrepancy between the various observations may be due to real variations in the particle spectra from event to event, but it is important to determine if this is the case. Taken as a whole, the various observations suggest that there is a local maximum in $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ at a few MeV/nucleon, as well as a gradual increase in $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ with increasing energy, for energies from about 10 to at least 100 MeV/nucleon. There are few reports of ^{3}He enrichments observed simultaneously at widely varying energies. Thus, the picture of ^{3}He-rich events is based primarily on observations of individual flares at different energies.

In this paper we present some additional observations of ^{3}He enhancements in solar energetic particle events. We discuss briefly our search for ^{3}He-rich events and some of the observed event parameters. The observations are then related to high energy observations made during the same time period with another instrument, the ONR-604 experiment on-board the Combined Release and Radiation Effects Satellite (CRRES). This is the first time a search for ^{3}He enhanced events has been conducted at such widely varying energies (0.3 - 3.1 & 50 - 110 MeV/nucleon).

1.2. CIR-associated events

Co-rotating interaction regions are created where high speed solar wind from coronal holes rams into slower solar wind streams. This interaction sometimes results in a pair of shocks, a forward shock moving outward ahead of the high speed wind and a reverse shock moving back towards the Sun in the solar wind frame. The shocks form beyond 1 AU and backwards streaming particles from the reverse shock are detected with interplanetary spacecraft. We term the events seen with HI-SCALE as CIR-associated events since we are seeing the particles at high latitudes, a long distance from the shock acceleration region.

The first comprehensive studies of ion abundances in CIR-associated events established that the relative ion abundances were different from those found for SEP events (McGuire et al. 1978; Scholer et al. 1979). These studies, as well as subsequent ones (Reames et al. 1991; Richardson et al. 1993), found that the C/O and He/O ratios were larger than those found in SEP events and that H/He ratios were smaller. It has been shown that

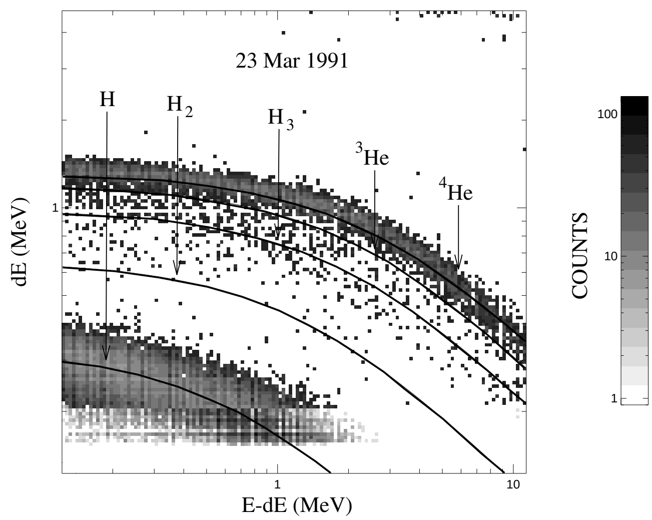

Fig. 1. Pulse height analysis histogram map of the energy loss in the thin forward detector vs the following detector. Plotted are the data for March 23, 1991, a period of high particle flux. Shown are the theoretical energy loss curves for some of the ion species detected with HI-SCALE (H, di-hydrogen, tri-hydrogen, ^{3}He, ^{4}He).

the C/O and He/O ratios are correlated with the high speed solar wind velocity (Richardson et al. 1993). McGuire et al. (1978), Reames (1992) and Richardson et al. (1993) have also noted that the abundance measurements are similar, though not identical, to those found in the high speed wind streams. However, there are also observations which show the C/O ratio in fast solar wind streams is significantly less than the C/O ratio in CIR's (von Steiger et al. 1992).

One particular note is that all of the earlier measurements of ion abundances in CIR-associated events have been made in the ecliptic plane. Also, we know of no reports of attempts to measure ^{3}He abundances in these events. Here we present the results of the first search for ^{3}He enhancements in high latitude CIR-associated events.

2. HI-SCALE/Ulysses description

The Heliosphere Instrument for Spectra, Composition, and Anisotropy at Low Energies (HI-SCALE; Lanzerotti et al. 1992) is used to measure the relative abundances of ions in interplanetary space. The flight path of Ulysses was such that the spacecraft was injected into an orbit about the Sun and out of the ecliptic plane. This 'solar polar' orbit was achieved via a gravitational assist from Jupiter in February, 1992. Thus, observations after February, 1992 were made as the spacecraft moved to high heliolatitudes. However, the spacecraft did not leave the equatorial streamer belt until about June, 1992.

Ion species are determined using a ΔE vs E telescope, the Composition Aperture (CA) telescope. The CA telescope consists of 3 silicon solid-state detectors, the configuration being that of a thin 5μ detector (detector D) followed by a 200μ detector (detector C), with an anti-coincidence detector behind that. Particle events are pulse height analysed (PHA) whereby the energy loss pulse heights in each of the first two detectors are recorded on a 2-dimensional histogram as in Fig. 1. The energy loss in the D detector is a function of the nuclear charge Z and the energy per mass of the detected particle. Thus, each ion species detected lies along a specific track in the 2-dimensional PHA space. The HI-SCALE instrument measures He ions with energies between 0.3 and 3.1 MeV/nucleon. Shown in Fig. 1 are tracks for some of the ion species detected. The locations of the tracks shown on the PHA map are determined from the theoretically expected ionization energy losses. Note that H_2 and H_3 are hydrogen molecules, not deuterium and tritium.

3. Data analysis

Events in the HI-SCALE data are identified as increases in the proton flux (0.4 - 0.8 MeV) measured by the CA detector accumulated in 6 hour time intervals. All data, from the instrument turn-on in Nov. 1990 to the end of 1994 have been examined, excluding the period when the spacecraft was within the magnetosphere of Jupiter. We also exclude data that is complex, i.e. where solar energetic particle events and CIR-associated events overlap.

A pulse height map (see Fig. 1) is created for each event and a histogram of the number of counts in the PHA map as a function of orthogonal distance from the ^{4}He centerline is made. The ^{4}He centerline is determined by a least-squares fit to a long term ($\sim$ 2 years) accumulation of data. Two examples of these histograms are shown in Fig. 2. These histograms, hereafter called ^{4}He centerline histograms, show one event with no ^{3}He enhancement (Fig. 2a) and one with a ^{3}He enhancement (Fig. 2b). The expected location of the ^{4}He peak is shown as bin 0, however, changes in the CA detector performance have caused a slight drift in the ^{4}He centerline position throughout the mission.

No centerline for ^{3}He can be found by the least-squares method used for the most commonly observed ion species, because the distribution of ^{4}He counts about their centerline is broad enough to overwhelm the counts in the expected location of the ^{3}He centerline. Instead, the expected ^{3}He position was found by calculating the theoretical ionization energy loss curves for ^{3}He and ^{4}He and plotting them on the 2-dimensional PHA maps. For each ^{4}He pixel, the shortest distance to the ^{3}He curve was found (d_{min}) and the average of all d_{min} was found to be 4.3$\pm$0.7 pixels. Thus, the expected location of ^{3}He counts on the ^{4}He centerline histograms is at -4.3 pixels. This method assumes that each event has a uniform distribution of counts along the entire curve. This is not the case, but is unlikely to greatly affect the result as the standard error in the average distance between the two curves is less than one pixel.

A comparison of Figs. 2a and 2b clearly shows that there is a marked asymmetry in the ^{4}He peak in Fig. 2b. Note that there is a small, but still noticeable asymmetry in Fig. 2a as well. The slight asymmetry in Fig 2a is assumed to be due to background events. The large asymmetry in Fig. 2b is believed to be due to an enhancement in the number of ^{3}He particles. It is clear that the ^{4}He peak cannot be fitted with a simple gaussian. In

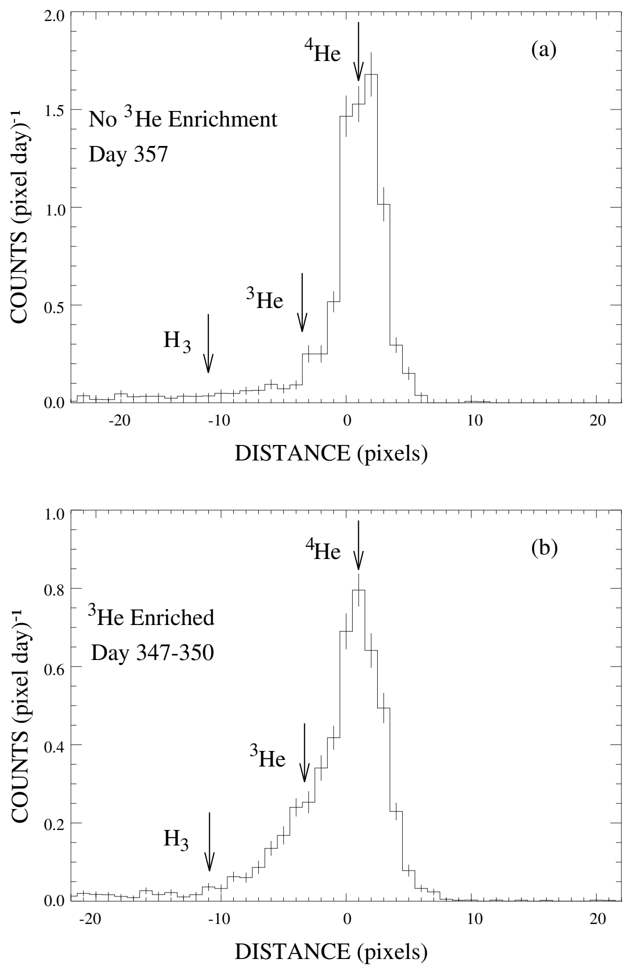

Fig. 2a and b. Histogram of number of counts as a function of distance from the ^{4}He centerline. The vertical arrows indicate the expected positions of ^{3}He and ^{4}He counts. For reference and scale, the expected location for tri-hydrogen is also shown. **a** Shows no apparent excess abundance of ^{3}He, **b** shows an enhancement in the abundance of ^{3}He.

order to determine $\Gamma(^3\text{He}/^4\text{He})$ for each event, the ^{4}He centerline histograms are all fit with 2 gaussian components plus a background component. The initial parameters of the first gaussian were chosen so that the centroid coincided with the ^{4}He peak and the location of the second gaussian was fixed to have a centroid 4.3 pixels to the left of the ^{4}He centroid. The width of the second gaussian was a fixed parameter as well.

The detector background has not been studied extensively, so the exact nature of the background is not known. However, a large number of the background counts are due to particles which pass through the thin, forward (ΔE) detector and then result in an incomplete energy loss in the following (E) detector. One possible example of such an interaction would be a cosmic-ray particle that after passing through the forward detector, collides with a side wall of the detector and ejects several particles, only some of which then interact in the following detector. Any ^{4}He ion that passes through the thin detector but does not deposit its full energy in the following detector would result in a background where counts would appear to the left of and below the ^{4}He centerline with no counts to the right of and above the centerline. Thus, in order to subtract background, we choose a simple step-function which has some finite value to the left of the ^{4}He position and is zero to the right.

The data have been divided into (1) ecliptic events: events detected before the encounter with Jupiter; (2) out-of-ecliptic events: events detected after the encounter with Jupiter; and (3) co-rotating interaction region (CIR) events: observed at high latitudes.

4. Results

4.1. SEP events

We determine $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ for all events by comparing the areas under the 2 gaussian curves derived from fits to a ^{4}He centerline histogram for each event. As a result of the width of and slight asymmetry in the ^{4}He gaussian, we find that there is an average level of background counts in the location of the ^{3}He track. We find that for $\sim$ 150 events, the average contribution of ^{4}He in the range where ^{3}He is expected is 0.095 ± 0.021. This was determined by taking the average of all events and then excluding all events with $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ more than 3σ above the average, and retaking the average, iterating until no events were excluded. The resulting average ratio is considered to be the detector background level. We only consider events that have $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ greater than 3σ above this background ($\Gamma(^3\mathrm{He}/^4\mathrm{He})$ = 0.157) to have a significant enhancement of ^{3}He. Note that this background prevents events with $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ less than a few percent from being measured.

The events which were found to have enhancements of $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ are listed in Table 1. Of 123 ecliptic events analyzed, only 14 events were found to have a significant $\Gamma(^3\mathrm{He}/^4\mathrm{He})$. Of 33 out-of-ecliptic events considered, 3 were found to have a significant enhancement in ^{3}He. Thus, an average of about 10% of the events in each case had ^{3}He enhancements. In Table 1, the event times are the best estimates of the interval when ^{3}He abundances were enhanced and do not necessarily correspond to any particular features in the ion counting rate plots. The $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ values are the background subtracted values.

4.2. CIR-associated events

None of the 26 CIR-associated events analyzed were found to have a significant enhancement in $\Gamma(^3\mathrm{He}/^4\mathrm{He})$. The CIR-associated events studied correspond to events numbered 2-28, skipping number 15 (see numbering in Simnett et al. 1994). Event number 15 was not included because an SEP event was detected at the same time as the CIR-associated event.

Despite our lack of a positive detection of ^{3}He in CIR-associated events, we are able to set an upper limit on $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ in the observed high latitude events. Setting this limit at 2σ above background, we find an upper limit of $\Gamma(^3\mathrm{He}/^4\mathrm{He}) \leq 4\%$.

5. Discussion

5.1. SEP events

It is difficult to extrapolate the HI-SCALE events back to specific flare events on the Sun. Part of the reason for this is the overall high level of activity, giving many candidate flare events for each increase in the HI-SCALE data. Thus, we are unable to comment in detail about how these events compare to previous observations of ^{3}He rich events. None of the ^{3}He enriched events are large, long-lasting SEP events. The ^{3}He enriched periods last for anywhere between about 8 hours and about 3 days, with $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ values of between 7% and 79%. Many, 10 out of 17, of the events occur within the first 4.5 months of the mission, likely reflecting dropping solar activity levels. We find nothing about the 17 events which would indicate that they are not similar to all previously observed ^{3}He-rich events.

In a recent paper by Chen et al. (1995), observations of ^{3}He-rich events from 1991 are reported for energies from 50-110 MeV/nucleon. They found 13 ^{3}He-rich events with the ONR-604 instrument on the CRRES spacecraft. Of the 13 events, 9 were GOES X-class X-Ray flares and the other 4 were GOES M6 or greater. Of the 9 X-class flares, 5 of them saturated the GOES X-ray monitors and are listed as X12 class events.

These flares, many of which came from the same active region, were some of the largest flares of the last solar maximum. The large radial and longitudinal separation of the Ulysses spacecraft from the Earth, and therefore from the CRRES satellite, does make absolute identification difficult in some cases. However, the extremely large size of the events simplifies the identification of them in the HI-SCALE data set. Positive identification of the ONR-604 events in the HI-SCALE data is made whenever there are large increases in the HI-SCALE detector that occur when the spacecraft is well connected with the flaring region on the Sun and/or when the large events occurred in isolation from other large events. We believe that HI-SCALE observed at least 6 events in common with the ONR-604 list of 13 events. These correspond to the events numbered 5, 6, 7, 12, 13, and 16 in Chen et al. (1995).

Of the 6 flares in common with Chen et al. we find that in only one case is there a significant enhancement in ^{3}He (Fig. 3). This is event number 16 from Chen et al. and event number 12 in Table 1. The one corresponding enrichment comes from only a small time interval of 8 hours, corresponding to an individual peak, during the larger overall enhancement lasting 5 days. This, coupled with the information that none of the other large SEP events show an enhancement, leads us to believe that this particular enhancement is due to a small event that occurred at about the same time as the large event.

The lack of coincident observations of ^{3}He enhancements by CRRES/ONR-604 and Ulysses/HI-SCALE can be used to constrain the picture of the relative energy spectra and therefore $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ that we showed in the introduction. The Chen et al. (1995) event 6 had the largest enhancement in ^{3}He of all 13 events, with $\Gamma(^3\mathrm{He}/^4\mathrm{He})$=6.3%. This event was also detected with Ulysses/HI-SCALE, but no enhancement in ^{3}He was found. If the power-law energy spectra for the event obtained

Table 1. HI-SCALE solar energetic particle events with enhancements in $\Gamma(^3He/^4He)$.

Event	Event Start yyddd/hhmm	Event End yyddd/hhmm	^{4}He Peak Rate (cm^2 s sr (MeV/nucleon))$^{-1}$	$\Gamma(^3He/^4He)$	S/C Dist. (AU)	S/C Dec. (deg.)
1	90326/0800	90328/1500	0.036±0.001	0.261±0.088	1.19	1.67
2	90332/0300	90333/1400	0.012±0.001	0.296±0.141	1.24	1.76
3	90339/0800	90339/1500	0.033±0.001	0.409±0.179	1.31	1.84
4	90345/1200	90347/0000	0.081±0.003	0.184±0.040	1.37	1.90
5	90347/1200	90350/0000	0.040±0.001	0.422±0.054	1.39	1.91
6	90359/0200	90362/0000	0.190±0.003	0.185±0.026	1.51	1.97
7	91009/1200	91012/1200	0.003±0.001	0.794±0.324	1.68	1.99
8	91015/0000	91016/0500	0.007±0.001	0.110±0.073	1.74	1.99
9	91020/0300	91022/0000	0.003±0.001	0.234±0.173	1.80	1.99
10	91051/2100	91055/1000	0.077±0.002	0.444±0.043	2.15	1.91
11	91262/1200	91263/0600	0.034±0.001	0.069±0.044	4.23	1.37
12	91274/1500	91274/2300	0.387±0.003	0.066±0.031	4.33	1.35
13	91278/0500	91279/1500	0.007±0.001	0.138±0.126	4.36	1.34
14	91344/2100	91346/0200	0.022±0.001	0.175±0.076	4.92	1.23
15	92076/1200	92077/0100	0.011±0.001	0.230±0.112	5.40	−0.86
16	92082/0000	92083/0000	0.013±0.001	0.146±0.070	5.40	−1.18
17	92131/1900	92132/1100	0.050±0.001	0.074±0.037	5.38	−3.62

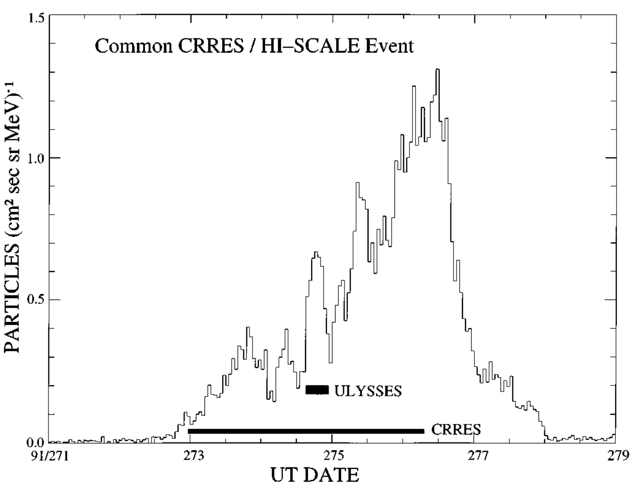

Fig. 3. Helium ion flux as detected by Ulysses/HI-SCALE for days 271 to 279 of 1991. This is event 12 in Table 1 and corresponds to event 16 from Chen et al. (1995). Shown are the times of ^{3}He enhancement reported by Chen et al. and those found for Ulysses/HI-SCALE in this study. Though the times overlap, it seems clear that the coincident ^{3}He enhancements are just a chance occurrence.

by Chen et al. are extrapolated down to the HI-SCALE energy range, then $\Gamma(^3He/^4He)$=0.03% is expected. This is much too small to be detected by HI-SCALE, and thus, our lack of an enhancement would confirm the picture obtained from the high energy observations that $\Gamma(^3He/^4He)$ decreases with decreasing energy. The overall picture seems to be clouded by including the results of Green et al. (1975) and Möbius et al. (1982), which show a local maximum in $\Gamma(^3He/^4He)$ at a few MeV/nucleon. The relative amplitude of the maximum is unknown though. This is because the ^{3}He enrichment is highly variable from flare to flare and there are few or no coincident observations of flares at these widely varying energies. Our results would be unable to detect enhancements of less than a few percent, suggesting that any local maximum at a few MeV/nucleon must be less than this.

In order to account for all of the observations, in particular Green et al. (1975) and Möbius et al. (1982), as well as the high energy observations, there must be a very significant flattening of the ^{4}He energy spectrum, or a steepening of the ^{3}He spectrum, in the range from 5-10 MeV/nucleon. Thus, physical models should be able to account for such a shift in the spectral shape. Such a shift, would be expected to be present in ^{3}He-rich flares and not in ^{3}He-poor flares. Also, due to the variability in $\Gamma(^3He/^4He)$, large variations in the emitted particle spectra must be allowed.

It has been suggested that the decreasing $\Gamma(^3He/^4He)$ with increasing event size is a result of a depletion of ^{3}He in the source region (Reames 1993). It is possible that the differences in the data presented here and in Chen et al. for these extremely large events occur because this depletion effect is not so severe at high (50-100 MeV/nucleon) as it is at lower energies.

Another plausible reason for the discrepancies is that the enhancements observed by Chen et al. resulted from flares other than the large X- and M-class flares they have attributed the enhancements to. Possibly, there were small, impulsive flares with enhancements in ^{3}He that occurred around the same times as the larger flares. The fluxes of the large events would mean the small events were unresolvable, so the ^{3}He from the small events would appear to be a part of the large events. The large number (13) of events seen by Chen et al. seems to suggest that this is unlikely to be the case, unless the ^{3}He-rich event rate is very high.

5.2. CIR-associated events

It is not surprising that no enhancement of ^{3}He is found in the CIR-associated events. As noted before, the ion abundances in

CIR-associated events are similar to those found in the solar wind, which itself has no enhancement of ^{3}He. The picture of ^{3}He enriched, impulsive, SEP events is that the enhancement is likely due to a preferential acceleration of ^{3}He and not a source abundance difference. Thus, this result of no enhancement indicates that there are different acceleration mechanisms operating in CIR's and in weak, impulsive flare events. The source populations for impulsive solar flares, which occur low in the corona, and for CIR's, which have a solar wind population, are not very different anyway. The differences being those between the closed field regions on the Sun (flares) and the open field regions (fast solar wind).

The acceleration mechanisms in CIR's are likely associated with the forward and reverse shocks. The overall picture of a CIR and the associated shock pair is quite well known. Our data indicate that the CIR shock acceleration mechanism does not preferentially accelerate ^{3}He relative to ^{4}He. A similar result is inferred from the lack of ^{3}He enhancements in large solar 'proton' events where the flare particles are also thought to be accelerated at a shock. The observational data suggest that impulsive solar flares cannot be modelled by shock acceleration alone. The inability of the CIR and 'proton' flare shock acceleration mechanisms to create enhancements of ^{3}He indicates that an additional, or different, mechanism is required for impulsive flares.

6. Conclusions

We have shown that the Ulysses/HI-SCALE instrument can detect ^{3}He. We have found 17 events with enhancements in $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ that greatly exceed the ambient solar ratios. These events are typical of previously observed ^{3}He-rich events. We are unable to corroborate the detection of ^{3}He enhancements in 13 very large solar flares observed with the CRRES/ONR-604 instrument. None of the events observed by both instruments are found to have enhancements in $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ in the HI-SCALE energy range. This lack of enhancement at low energies is different from what we had expected based on previous observations of ^{3}He-rich events. However, there is still a possibility of a significant enhancement that is below the detection threshold of HI-SCALE. The existence of a local maximum in $\Gamma(^3\mathrm{He}/^4\mathrm{He})$ at a few MeV/nucleon is not verified, but its amplitude is limited to about 6% by our results. A more complete picture of ^{3}He-rich events requires simultaneous observations of these events over a large energy range, from a few 100 kev/nucleon to about 100 MeV/nucleon. Also, we were unable to detect any enhancements of ^{3}He in high-latitude CIR-associated events. Thus, we conclude that the acceleration mechanism in CIR's does not preferentially accelerate ^{3}He relative to ^{4}He. We also conclude that the particle acceleration mechanism in CIR's is not the same as that responsible for accelerating particles in ^{3}He-rich solar flares.

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