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MeV ^{3}He/^{4}He isotope abundances in solar energetic particle events: A systematic survey of SOHO/COSTEP observations

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Abstract. We present first results based on a systematic survey of 4-41 MeV/N 3He/4He isotope abundances with ratios >0.01 detected by the COmprehensive SupraThermal and Energetic Particle analyzer (COSTEP) onboard the SOHO (SOlar and Heliospheric Observatory) spacecraft. More than about 25% of the identified events showed 3He/4He ratios in the range 0.1-1. For events with sufficiently high detector count rates the atomic mass plots can be resolved up to a time resolution of about 1 hour. These events are most suitable for comparisons with in situ solar wind plasma and magnetic field measurements and SOHO's optical white-light and extreme ultraviolet (EUV) observations of the Sun. The correlations show an association with passages of shock associated coronal mass ejections (CMEs) in the solar wind that inhibit high He/H plasma overabundances. It is likely that the CMEs have been released in strong magnetic reconfiguration processes at the solar source sites. Here we present a brief overview of such an event detected on October 30, 2000.

1. Introduction

The SOHO/COSTEP instrument measures solar energetic particles (SEPs) at MeV energies in the interplanetary medium. The solid state detectors are capable to detect ^{3}He/^{4}He-enrichments at these energies (Müller-Mellin et al., 1995). Usually, the ^{3}He/^{4}He-ratio in the solar wind is at the order of 10^{-4}, but occasionally ratios up to about values of ~1 or even above have been observed in SEP events (e.g., Mason et al., 1999). The origin of these isotope abundances has commonly been attributed to impulsive solar flares and wave-particle interaction mechanisms (Temerin and Roth, 1992). However, fully satisfying physical explanations are still lacking. Here we present first results of a systematic survey of the He-measurements taken by COSTEP since launch in 1995 until the end of the year 2000.

2. Data

For this study we have analyzed SOHO/COSTEP measurements of 4.3-40.9 MeV/N helium particles as well as COSTEP data covering proton and electron measurements at energies below 10 MeV. These data were compared with magnetic field and plasma data from the Advanced Coposition Explorer (ACE), SOHO/LASCO (Large Angle Spectroscopic COronagraph) observations of CMEs and X-ray flare measurements taken by the GOES satellite.

3. Identification of ^{3}He/^{4}He-rich events

Figure 1 shows an example of a ^{3}He/^{4}He-rich event as identified from the COSTEP mass separation plot for Oct. 30, 2000. The vertical axis in Figure 1 provides information about the detector count rates, the horizontal axis is labelled such that ^{4}He corresponds to a value of 0. The two largest peaks in the count rates at –0.6 and 0 correspond to proton (-0.6) and ^{4}He particles. The presence of a major contribution of ^{3}He isotopes at about –0.05 is very distinguished. The ratio of ^{3}He/^{4}He was 0.7 (see Table 1, doy 304 in 2000). All identified ratios >0.01 are listed in Table 1.

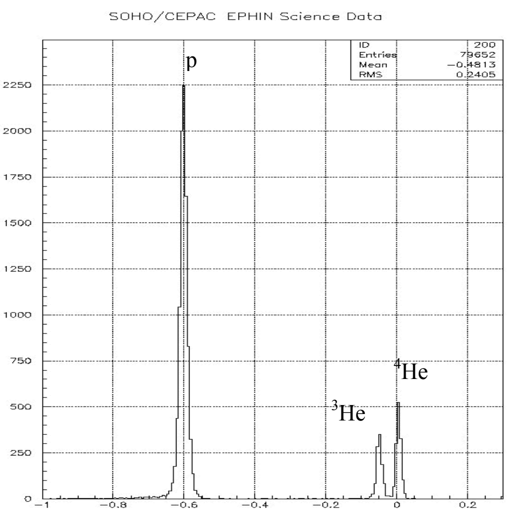

Figure 1. COSTEP mass plot for 30 October 2000. The peaks at –0.6, -0.05 and 0 correspond to p, ^{3}He and ^{4}He.

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Table 1. ^{3}He/^{4}He-rich (>0.01) days identified in SOHO/COSTEP data (4.3-40.9 MeV/N) until the end of 2000. Notes: p, ^{3}He and ^{4}He peaks are given in total counts (parallel detector segments) based on maximums of daily mass plots (as all mass plots are binned to the same histogram, this number can be used for relative comparison of ^{3}He and ^{4}He (and to protons)); the mass plots do not take into account special instrument configurations like ring segment offs; bold values denote ^{3}He/^{4}He-ratios ≥0.1.

Year	DoY	p peak	^{3}He peak	^{4}He peak	^{4}He/p	^{3}He/^{4}He
1995						
1996	**121**	**14**	**5**	**20**	**1.429**	**0.250**
	191	645	6	211	0.327	0.028
	334	7962	9	537	0.067	0.017
	335	8148	12	803	0.099	0.015
1997	**063**	**17**	**6**	**16**	**0.941**	**0.375**
	092	1634	4	89	0.054	0.045
	223	**83**	**10**	**57**	**0.687**	**0.175**
	261	337	8	84	0.249	0.095
	262	**190**	**13**	**51**	**0.268**	**0.255**
	264	**1032**	**7**	**66**	**0.064**	**0.106**
	308	4940	37	3305	0.669	0.011
*	310	7517	49	2920	0.388	0.017
*	312	6986	62	5438	0.778	0.011
	318	4142	8	346	0.084	0.023
	332	**321**	**16**	**75**	**0.234**	**0.213**
	333	**157**	**10**	**35**	**0.223**	**0.286**
1998	095	3007	8	601	0.200	0.013
	097	3908	9	698	0.179	0.013
	113	6679	82	5314	0.796	0.015
	114	3617	35	3071	0.849	0.011
	115	3028	19	1624	0.536	0.012
*	122	2293	11	574	0.250	0.019
*	123	4368	27	1670	0.382	0.016
*	124	4130	23	1837	0.445	0.013
	126	6796	102	3486	0.513	0.029
	127	7621	33	2482	0.326	0.013
	128	2832	7	189	0.067	0.037
	132	1906	7	237	0.124	0.030
	148	9097	13	559	0.061	0.023
	149	**5209**	**48**	**383**	**0.074**	**0.125**
	169	9456	15	1258	0.133	0.012
	309	**207**	**9**	**22**	**0.106**	**0.409**
*	310	16424	28	2089	0.127	0.013
*	311	15831	66	2008	0.127	0.033
*	312	13171	178	3178	0.241	0.056
	313	**7436**	**56**	**300**	**0.040**	**0.187**
	314	**2907**	**6**	**58**	**0.020**	**0.103**
	326	5525	5	201	0.036	0.025
	327	4695	7	239	0.051	0.029
	344	**119**	**5**	**18**	**0.151**	**0.278**
	352	**650**	**5**	**24**	**0.037**	**0.208**
1999	070	657	7	38	0.058	0.184
	080	**127**	**8**	**20**	**0.157**	**0.400**
	081	**42**	**11**	**7**	**0.167**	**1.571**
*	128	14360	7	561	0.039	0.012
	129	7167	9	197	0.027	0.046
	130	6785	11	536	0.079	0.021
	132	**2523**	**12**	**65**	**0.026**	**0.185**
*	155	7574	40	3201	0.423	0.012
*	158	8584	18	1640	0.191	0.011
	164	2960	9	102	0.034	0.088
	169	**1521**	**45**	**168**	**0.110**	**0.268**
	170	**1807**	**36**	**139**	**0.077**	**0.259**
	171	1374	6	70	0.051	0.086
	174	6191	19	431	0.070	0.044
	175	4766	9	218	0.046	0.041
	176	10332	5	354	0.034	0.014
	181	**1019**	**8**	**54**	**0.053**	**0.148**
	182	1469	8	81	0.055	0.099
	183	**910**	**5**	**33**	**0.036**	**0.152**
	188	**399**	**6**	**53**	**0.133**	**0.113**
	193	**139**	**4**	**32**	**0.230**	**0.125**
	194	**1179**	**30**	**117**	**0.099**	**0.256**
	195	**421**	**8**	**34**	**0.081**	**0.235**
	218	**702**	**4**	**35**	**0.050**	**0.114**
	219	**648**	**7**	**10**	**0.015**	**0.700**
	226	**409**	**14**	**62**	**0.152**	**0.226**
	227	**174**	**6**	**28**	**0.161**	**0.214**
	236	**116**	**6**	**8**	**0.069**	**0.750**
	258	6771	6	185	0.027	0.032
	264	1488	5	103	0.069	0.049
	289	1621	5	131	0.081	0.038
	290	2409	5	128	0.053	0.039
	305	**33**	**5**	**7**	**0.212**	**0.714**

	329	**381**	**7**	**41**	**0.108**	**0.171**
	330	**270**	**5**	**39**	**0.144**	**0.128**
	337	**249**	**6**	**5**	**0.020**	**1.200**
	344	14042	8	144	0.010	0.056
	358	**1915**	**31**	**85**	**0.044**	**0.365**
	359	**1379**	**18**	**46**	**0.033**	**0.391**
	360	**424**	**8**	**15**	**0.035**	**0.533**
	361	**748**	**5**	**46**	**0.061**	**0.109**
	363	636	9	385	0.605	0.023
	365	9155	12	797	0.087	0.015
2000	002	10496	8	653	0.062	0.012
	018	1149	15	546	0.475	0.027
	019	5244	14	147	0.028	0.095
	030	11939	16	1450	0.121	0.011
	062	**639**	**4**	**30**	**0.047**	**0.133**
	065	**455**	**4**	**19**	**0.042**	**0.211**
	107	**95**	**4**	**36**	**0.379**	**0.111**
	118	**2856**	**7**	**23**	**0.008**	**0.304**
	122	884	17	1420	1.606	0.012
	125	404	7	122	0.302	0.057
	126	1681	10	294	0.175	0.034
	127	5393	6	292	0.054	0.021
	138	6469	16	1376	0.213	0.012
	144	7516	15	386	0.051	0.039
	145	**2003**	**137**	**638**	**0.319**	**0.215**
	146	953	6	106	0.111	0.057
	163	12458	20	1824	0.146	0.011
	165	13761	4	156	0.011	0.026
	168	4985	17	1134	0.227	0.015
	170	8404	21	1284	0.153	0.016
	171	**4101**	**53**	**299**	**0.073**	**0.177**
	172	**1045**	**10**	**59**	**0.056**	**0.169**
	174	4469	7	133	0.030	0.053
	175	9801	13	687	0.070	0.019
	176	4925	11	518	0.105	0.021
	177	9630	27	2218	0.230	0.012
	180	6454	6	230	0.036	0.026
	181	9515	9	476	0.050	0.019
	193	3690	8	187	0.051	0.043
	194	5672	10	534	0.094	0.019
	202	4767	28	2619	0.549	0.011
	223	4437	5	109	0.025	0.046
	224	12709	15	1115	0.088	0.013
	225	6280	18	1164	0.185	0.015
	235	**206**	**25**	**28**	**0.136**	**0.893**
	236	**75**	**19**	**22**	**0.293**	**0.864**
	259	13141	40	3699	0.281	0.011
	261	15400	51	3934	0.255	0.013
	262	8397	6	386	0.046	0.016
	263	4389	5	337	0.077	0.015
	264	7349	9	573	0.078	0.016
	265	6188	8	176	0.028	0.045
	271	**682**	**15**	**38**	**0.056**	**0.395**
	272	**788**	**3**	**16**	**0.020**	**0.188**
	284	2587	3	47	0.018	0.064
	285	8465	6	117	0.014	0.051
	286	8977	5	145	0.016	0.034
	287	5544	14	341	0.062	0.041
	288	**1494**	**25**	**49**	**0.033**	**0.510**
	289	**639**	**4**	**16**	**0.025**	**0.250**
	292	12006	29	2389	0.199	0.012
	293	10654	10	901	0.085	0.011
	300	16020	24	1504	0.094	0.016
	301	18067	13	812	0.045	0.016
	303	**4018**	**31**	**71**	**0.018**	**0.437**
	304	**2247**	**350**	**523**	**0.233**	**0.669**
	305	6761	42	1720	0.254	0.024
	316	3778	80	2318	0.614	0.035
	317	2016	20	1820	0.903	0.011
	318	1378	13	980	0.711	0.013
	319	1665	11	1024	0.615	0.011
	320	1634	12	845	0.517	0.014
	335	3778	10	936	0.248	0.011
	363	**518**	**11**	**52**	**0.100**	**0.212**

* SEP ^{3}He Enhancements reported by Mason et al., 1999.

3. Fine-scale characteristics

The ^{3}He/^{4}He-rich event October 30, 2000 had suffciently high count rates (compare with Table 1) that made it possible to investigate the fine-scale characteristics of the event by using a time resolution up to 1 hour as shown in Figure 2. In this event the ^{3}He increase occurred during transition from October 29 to 30 (doys 303-304) with the highest ^{3}He levels staying until the end of October 30 (doy 304). After that time the ^{3}He level dropped in contrast to the further rising proton and helium values.

4. Comparison with solar wind measurements

Figure 3 shows a comparison with ACE solar wind plasma and magnetic field data (courtesy CDAW, D. J. McComas).

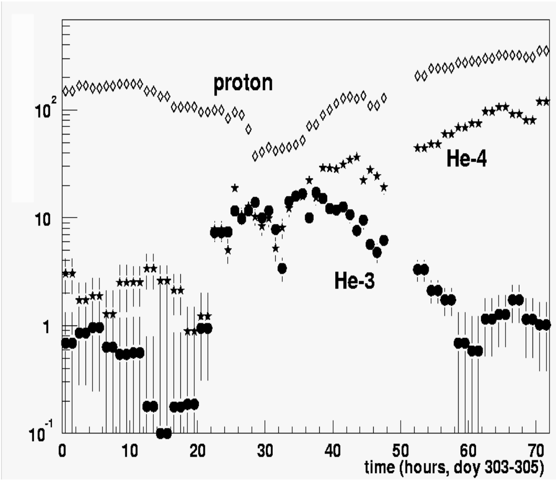

Figure 2. Hourly values of proton, ^{4}He and ^{3}He count rates measured for the period October 29 to 31 (doys 303-305) in 2000 by SOHO/COSTEP.

ACE detected a shock passage followed by a huge flux rope type CME (magnetic cloud). There might have been a reverse shock following the CME, but this needs further study.

Figure 3 shows somehow surprisingly, that the ^{3}He/^{4}He-enrichment measured at MeV energies corresponds to a solar wind He/p-enrichment following the trailing edge of the typical magnetic cloud signatures. The plasma and magnetic field signatures appear to be similar to the classical January 10/11, 1997 event that has been described by Burlaga et al. (1998). It has to be clarified by further analyses whether this association is by chance or might be of importance for the understanding of the origin and interplanetary evolution of such events.

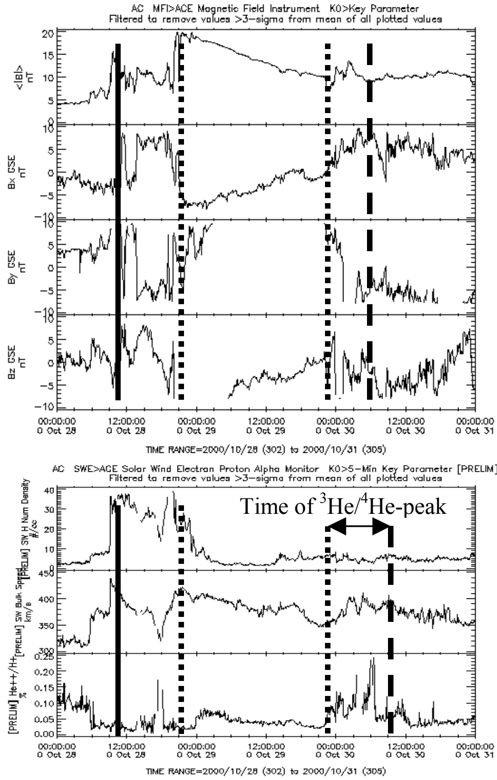

Figure 3. Solar wind plasma and magnetic field data measured by ACE from October 28 to October 31, 2000. Top to bottom: Magnetic field strength, cartesian components of the field, proton number density, bulk speed and He/p-ratio. The solid line denotes the shock ahead of the CME (bounded by dotted lines) followed by a region that might be prominence material (between solid and dashed lines).

5. Associations with solar activity

The comparison with GOES X-ray flare observations showed no direct correspondence to the onset of the ^{3}He/^{4}He enrichment seen in the energetic particles. The in situ detected CME in the solar wind can be traced back to a halo CME on October 25 observed by the SOHO/ LASCO coronagraphs. The event is typical in the sense that we did not find a good correlation so far of large ($\geq$0.1) ^{3}He/^{4}He-enrichments at MeV energies with solar flares.

6. Summary

Through a systematic survey of He-measurements at MeV energies provided by the SOHO/COSTEP instrument we identified ^{3}He/^{4}He isotope abundances with ratios $\geq$0.01 from the beginning of the mission until the end of 2000. The events listed in Table 1 can serve as a valuable tool for further investigations.

We found that large ($\geq$0.1) ^{3}He/^{4}He-enrichments at these energies did not show a direct correspondence to solar flares, but rather to in situ passages of CMEs. There is some indication for an association with large He/p-enhancements in the transient solar wind plasma associated with CME passages, indicative of special conditions of the solar source regions were the CMEs had been released. The solar source and in situ conditions of large ^{3}He/^{4}He-enrichments at MeV energies need further studies to clarify their origins in more detail.

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