



HAL
open science

A survey of ^3He enhancements at $2\text{--}20$ MeV/nucleon: Ulysses COSPIN/LET

C. Tranquille, R. G. Marsden, T. R. Sanderson, M. Y. Hofer

► **To cite this version:**

C. Tranquille, R. G. Marsden, T. R. Sanderson, M. Y. Hofer. A survey of ^3He enhancements at $2\text{--}20$ MeV/nucleon: Ulysses COSPIN/LET. *Annales Geophysicae*, 2003, 21 (6), pp.1245-1248. hal-00317073

HAL Id: hal-00317073

<https://hal.science/hal-00317073>

Submitted on 18 Jun 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

A survey of ^3He enhancements at 2–20 MeV/nucleon: Ulysses COSPIN/LET observations

C. Tranquille, R. G. Marsden, T. R. Sanderson, and M. Y. Hofer

Research and Scientific Support Department of ESA, ESTEC, 2200 AG Noordwijk, The Netherlands

Received: 27 July 2002 – Revised: 24 October 2002 – Accepted: 28 October 2002

Abstract. We present the results of a survey of enhancements in the ratio of $^3\text{He}/^4\text{He}$ as measured by the COSPIN/LET instrument on board the Ulysses spacecraft in the energy range 2–20 MeV/n. In the context of this study, all ratios of $^3\text{He}/^4\text{He}$ above 0.05 are considered to be enhanced compared with the solar system value of ~ 0.0004 . Previous studies have shown that enhanced fluxes of ^3He are frequently associated with small, impulsive solar flare events in which the observer is well connected to the flare site. These events also often show enrichments in heavy ion composition compared with standard coronal values. Recent attention has also focused on ^3He enrichments as evidence for re-acceleration of remnant particle populations that are present in the inner heliosphere following periods of enhanced solar activity. For this study, we have examined the Ulysses data set from launch (October 1990) up to the present, representing a full solar cycle. The spatial coverage extends from 1–5.4 AU in heliocentric distance, and effectively includes the complete range of heliomagnetic latitudes from pole to pole. We have identified 12 periods of enhanced $^3\text{He}/^4\text{He}$, occurring at heliocentric distances out to 5 AU, and helio-latitudes up to 48° . We investigate the characteristics of the events, many of which last for several days, in order to establish possible origins.

Key words. Interplanetary physics (energetic particles) – Solar physics, astrophysics and astronomy (energetic particles; flares and mass ejections)

1 Introduction

The ambient solar system value for the $^3\text{He}/^4\text{He}$ ratio has been shown to be ~ 0.0004 by studying helium abundances in the slow solar wind (Gloeckler and Geiss, 1998) and solar prominences (Hall, 1975). Early in situ observations of energetic ions indicated that a low value for the $^3\text{He}/^4\text{He}$ ratio

was also valid for large solar energetic particle (SEP) events (Mewaldt et al., 1984). Such events are termed “gradual” because of their association with soft solar X-ray emission characterised by a slow onset and relatively long decay phase. The dominant acceleration processes for gradual events are CME (coronal mass ejection) driven shocks, which energize protons more efficiently than heavier ions. A second class of SEP event, termed “impulsive” because of a rapid, short-lived rise in solar X-ray activity and radio emissions, have been shown to provide enhanced ^3He populations (Reames et al., 1988), with the ratio to ^4He fluxes increasing by up to 10^4 times that of the solar system value. Impulsive events have in general smaller fluences than gradual events and are also characterised by elevated fluxes of heavier ions, most notably Fe (Mason et al., 1986). A review of the acceleration mechanisms and characteristics associated with both types of SEP events can be found in Reames (1999).

Recent measurements by more sensitive energetic ion spectrometers on board the Advanced Composition Explorer (ACE) spacecraft indicate that the above classification of ^3He populations in SEP events is not so rigid, and that enhanced $^3\text{He}/^4\text{He}$ ratios have also been measured during large SEP events (Wiedenbeck et al., 2000). A possible explanation for such observations requires the re-acceleration of a ^3He remnant population seeded in the interplanetary medium by an earlier impulsive SEP event (Mason et al., 1999; Desai et al., 2001).

In this study, we make a systematic survey of ^3He abundances at 2–20 MeV/n using COSPIN/LET measurements made by Ulysses throughout the complete mission, and attempt to correlate our results with features in the solar wind and magnetic field data, and heavy ion fluxes. A previous search for ^3He rich events using Ulysses HI-SCALE data (Biesecker, 1996) catalogued such events at low heliographic latitudes before the spacecraft embarked on the first pass of the southern solar polar regions. However, no evidence of ^3He enhancements was found at higher latitudes in co-rotating interaction regions in their study.

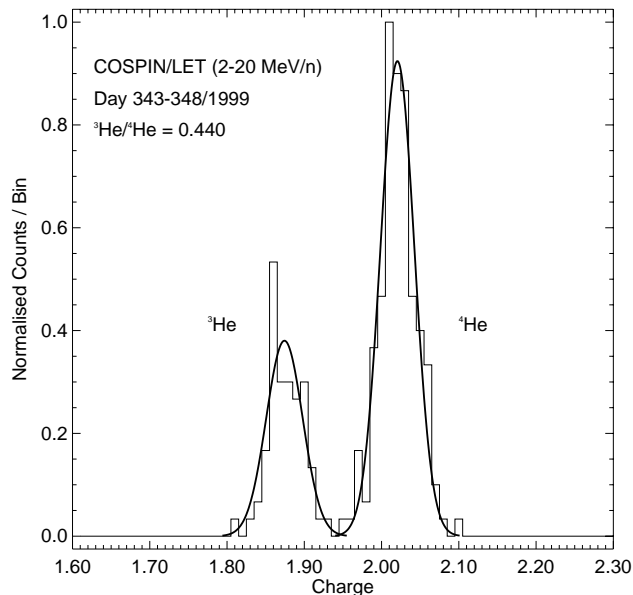


Fig. 1. An example of the charge histograms obtained from the D1:D2 pair of detectors for a ^3He rich event. The ^3He and ^4He populations are easily separated and are well-defined by standard Gaussian fits. Integrating the two Gaussian functions and taking their ratios yields the $^3\text{He}/^4\text{He}$ ratios used in this study. The histograms have been normalised to the maximum number of counts accumulated in a single charge bin during the complete event.

2 Instrumentation

The data used in this analysis were obtained from the Low Energy Telescope (LET) of the Cosmic Ray and Solar Particle Investigation (COSPIN) flown on board the Ulysses spacecraft (Simpson et al., 1992). The LET instrument measures the flux, energy spectra and ion composition of solar energetic particles and low energy cosmic ray nuclei in the energy range of ~ 1 MeV/n to ~ 75 MeV/n. The instrument uses the standard dE/dX vs. E technique to provide pulse height analysis (PHA) information, allowing for the identification of the chemical species and the energy of individual particles. The telescope is also able to provide counting rate information of protons, alpha particles and groups of particle species in fixed energy channels. The present study will focus primarily on PHA data of 2–20 MeV/n helium ions, using the D1 and D2 pair of solid state detectors. Data from the Ulysses magnetometer (Balogh et al., 1992) and the solar wind instrument (Bame et al., 1992) have also been used in this study.

3 Observations and discussion

Soon after the launch of Ulysses, the COSPIN/LET instrument measured a ^3He rich event (Simpson et al., 1992), which was clearly seen in the D1:D2 pulse height matrix plot as a separate track from the ^4He track. The corresponding signature in the D1:D2 charge histogram also provided

Table 1. The 12 periods of enhanced ^3He fluxes identified in this study with an event integrated ratio of $^3\text{He}/^4\text{He}$ exceeding 0.05. The table provides details of the date and location (heliocentric distance (R) and helio-latitude) of each event, and the derived $^3\text{He}/^4\text{He}$ ratio

Event	Year	Day of Year	R (AU)	Helio-Latitude	$^3\text{He}/^4\text{He}$
A	1990	300-302	1.03	4.98	0.110 ± 0.010
B	1990	311-315	1.09	3.78	0.303 ± 0.022
C	1990	332	1.24	1.84	0.197 ± 0.084
D	1990	345-350	1.39	0.48	0.389 ± 0.016
E	1990	359-363	1.53	-0.49	0.164 ± 0.006
F	1991	051-055	2.16	-3.00	0.335 ± 0.019
G	1991	080-081	2.46	-3.68	0.077 ± 0.004
H	1999	096-097	5.02	-24.10	0.209 ± 0.032
I	1999	343-348	4.25	-40.36	0.440 ± 0.064
J	2000	007-009	4.13	-42.56	0.825 ± 0.155
K	2001	086	1.49	-36.34	0.395 ± 0.126
L	2002	106	3.25	48.45	0.170 ± 0.050

a clean separation between the two helium isotopes, with two well separated histograms, both allowing excellent fits to Gaussian profiles. This signature was used to systematically search the complete LET pulse height data set for elevated levels of the $^3\text{He}/^4\text{He}$ ratio, indicating enhanced ^3He populations. An example of the resolution of ^3He and ^4He using the charge histogram technique is shown in Fig. 1.

A ratio of counts between the two helium isotopes exceeding 0.05 and the ability to fit the histograms to Gaussian functions with centre lines in the expected location, were used as criteria to define periods of enriched ^3He . A total of 12 such events were found during the complete Ulysses mission. Figure 2 shows the spatial distribution of these events (labelled A to L) along the Ulysses orbit, and Table 1 summarises their dates, positions and the derived $^3\text{He}/^4\text{He}$ ratios. Colour coded along the trajectory is the PHA derived 4–6 MeV/n helium intensity, which is used to indicate the level of solar activity. The in-ecliptic transit to Jupiter took place near solar maximum and seven ^3He rich events (A–G) were seen. After early 1991, enhanced levels of ^3He were not seen again until the next peak in the solar activity cycle, indicating a clear solar cycle dependence. The remaining out of ecliptic events (H–L) all occur in the southern heliosphere, with the exception of the last event (L) which was recently recorded in the Northern Hemisphere as Ulysses made its way back down to the ecliptic plane. This is most likely due to the phasing of the Ulysses mission with the solar cycle, as opposed to any underlying asymmetry between the two solar hemispheres. What is apparent from Fig. 2 is that the ^3He rich events identified in this study generally do not occur during large events with high helium and proton intensities (e.g. Hofer et al., 2003). This would indicate a preference for the impulsive class of events. It may be that for the more intense events, the signature of ^3He ions is masked in the spill over of the dominant ^4He histogram contribution.

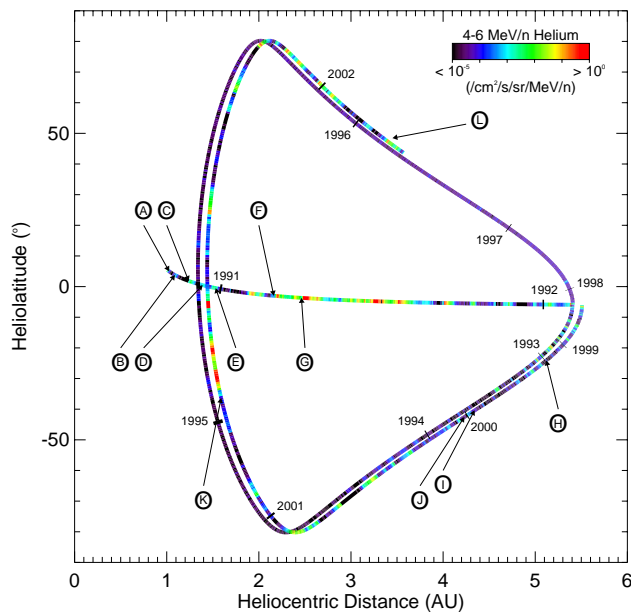


Fig. 2. The Ulysses trajectory plotted as a function of heliocentric distance and helio-latitude from launch in (October 1990) to May 2002. The second orbit is slightly displaced from the true orbit, in order to separate it from the first pair of polar passages for clarity. Colour-coded along the Ulysses trajectory is the PHA derived 4–6 MeV/n helium intensity measured by the COSPIN/LET instrument. The 12 periods of ^3He enrichments identified in this study have been labelled as events A to L on this diagram. Events A–G took place during the in-ecliptic transfer to Jupiter (launch to February 1992), and the remaining events (H–L) were during the high-latitude phase of the mission.

Conversely, we see no evidence for enhanced fluxes of heavy ions in the COSPIN/LET data during the identified events, as might be expected in the impulsive model. This observation could be due to the fact that the events were relatively weak, thereby producing heavy ion intensities that were too low for the sensitivity of the LET instrument. Furthermore, the energy threshold of the instrument increases for heavier ions (approximately 3 MeV/n and 4 MeV/n for oxygen and iron, respectively). Increased heavy ion fluxes are, however, clearly seen during large SEP events (Hofer et al., 2003).

The 12 events do not seem to correspond to any salient features in the solar wind or magnetic field observations which, if present, might indicate particle confinement or association with local travelling shocks. As an example, Fig. 3 shows solar wind and magnetic field data for a 26-day period centred about event I, together with proton and helium data obtained from the rate channels of the LET instrument. There are no significant features in any of the profiles during the period of enhanced ^3He . This observation is generally true for all of the ^3He rich events identified in this report. A careful analysis of the exact onset time of the ^3He enhancements may provide some correlation with small-scale features in the solar wind or magnetic field which have been missed in this study. An attempt to associate the ^3He rich events with so-

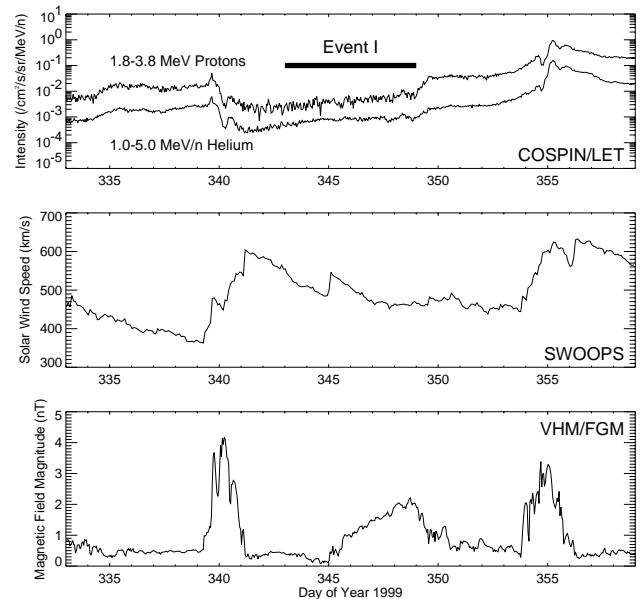


Fig. 3. The top panel shows 1.8–3.8 MeV protons and 1–5 MeV/n helium intensities (obtained from rate channels of the LET instrument) for a 26-day period centred about event I in 1999. The middle panel shows the solar wind speed variations as measured by the solar wind instrument (SWOOPS), and the bottom panel shows the magnetic field magnitude obtained from the magnetometer (VHM/FGM) on board Ulysses.

lar X-ray or radio emissions remains a future task and may provide direct evidence of a coronal origin for the ^3He .

In Fig. 4 we plot the derived $^3\text{He}/^4\text{He}$ ratios as a function of helio-latitude (top panel). There appears to be an increase in the ratio of the two isotopes with increasing helio-latitude. We are, however, aware that this tentative observation suffers from a relatively small sample of valid events. Furthermore, previous in-ecliptic measurements of the ratio have recorded values greater than 10 and show the variability of ^3He populations. No correlation is seen if the $^3\text{He}/^4\text{He}$ ratios are ordered according to heliocentric distance (bottom panel).

4 Conclusions

The COSPIN/LET instrument provides good resolution of 2–20 MeV/n ^3He and ^4He isotopes, allowing for the identification of 12 distinct ^3He rich events during the Ulysses mission to date. These events are spatially distributed across the complete heliocentric distance range of the Ulysses mission, and span to moderately high helio-latitudes, providing the first in situ observations of non-ecliptic energetic ^3He populations. There is a tentative correlation between events having a high $^3\text{He}/^4\text{He}$ ratio and increasing helio-latitude, although this may be a consequence of the relatively low number of events identified. However, there is no apparent indication of the origin of the ^3He populations from signatures in the solar wind or magnetic field.

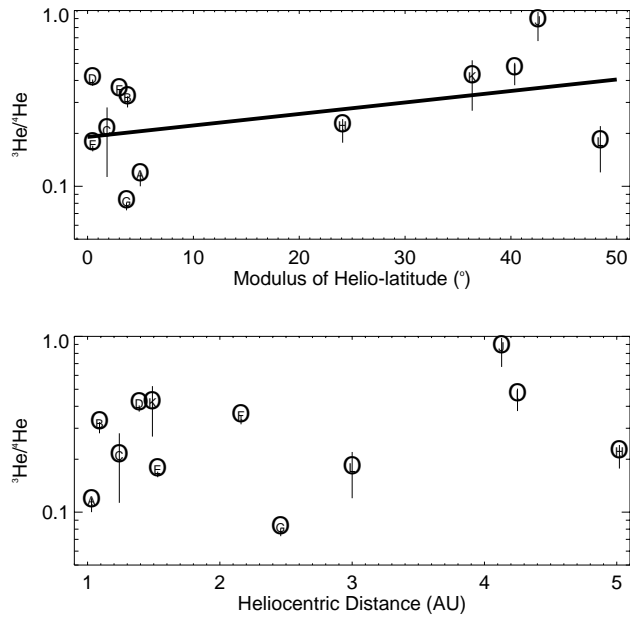


Fig. 4. Values of the derived $^3\text{He}/^4\text{He}$ ratio for each of the 12 events plotted against helio-latitude (top panel) and heliocentric distance (bottom panel). Statistical errors for each of the two isotope populations are combined to give an estimation of the error in the $^3\text{He}/^4\text{He}$ ratio. There is an indication that higher values occur with increasing helio-latitude. The straight line drawn in this figure is a least-squares fit to all the data points and has a chi-square value of 0.72.

Acknowledgements. We thank A. Balogh and D.J. McComas for use of Ulysses magnetometer and solar wind data, respectively. We acknowledge the use of the Ulysses Data System in the preparation of this paper.

Topical Editor R. Forsyth thanks two referees for their help in evaluating this paper.

References

- Balogh, A. et al.: The magnetic field investigation on the Ulysses mission: Instrumentation and preliminary scientific results, *Astron. Astrophys. Suppl.*, 92(2), 221, 1992.
- Bame, S. J. et al.: The Ulysses solar wind plasma experiment, *Astron. Astrophys. Suppl.*, 92(2), 237, 1992.
- Biesecker, D. A.: A search for ^3He enhancements in SEP and CIR-associated events with Ulysses/HI-SCALE, *Astron. Astrophys.*, 316, 487, 1996.
- Desai, M. I., Mason, G. M., Dwyer, J. R., Mazur, J. E., Smith, C. W., and Skoug, R. M.: Acceleration of ^3He nuclei at interplanetary shocks, *Ap. J.*, 553, L89, 2001.
- Gloeckler, G. and Geiss, J.: Measurements of the abundance of helium-3 in the sun and in the local interstellar cloud with SWICS on Ulysses, *Space Sci. Rev.*, 84, 275, 1998.
- Hall, D. N. B.: Spectroscopic detection of solar He-3, *Ap. J.*, 197, 509, 1975.
- Hofer, M. Y., Marsden, R. G., Sanderson, T. R., and Tranquille, C.: From the sun's south to the north pole – Ulysses COSPIN/LET composition measurements at solar maximum, *Ann. Geophysicae*, this issue, 2003.
- Mason, G. M., Reames, D. V., von Rosenvinge, T. T., Klecker, B., and Hovestadt, D.: The heavy-ion compositional signature in He-3-rich solar particle events, *Ap. J.*, 303, 849, 1986.
- Mason, G. M., Mazur, J. E., and Dwyer, J. R.: ^3He enhancements in large solar energetic particle events, *Ap. J.*, 525, 133, 1999.
- Mewaldt, R. A., Spalding, J. D., and Stone, E. C.: A high-resolution study of the isotopes of solar flare nuclei, *Ap. J.*, 280, 892, 1984.
- Reames, D. V.: Particle acceleration at the sun and in the heliosphere, *Space Sci. Rev.*, 90, 413, 1999.
- Reames, D. V., Dennis, B. R., Stone, R. G., and Lin, R. P.: X-ray and radio properties of solar (He-3) rich events, *Ap. J.*, 327, 998, 1988.
- Simpson, J. et al.: The Ulysses cosmic ray and solar particle investigation, *Astron. Astrophys. Suppl.*, 92(2), 365, 1992.
- Wiedenbeck, M. E. et al.: Enhanced abundances of ^3He in large solar energetic particle events, *ACE 2000 Symposium*, 107, 2000.