Light Isotope Abundances in Solar Energetic Particles Measured by the NINA-2 Instrument

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Abstract

The instrument NINA-2 flew on board the satellite MITA between July 2000 and August 2001, in circular polar orbit. This paper reports about a set of Solar Energetic Particle events measured by the NINA-2 instrument. The detector has mass resolution of about 0.15 amu for light nuclei and gives the possibility to observe hydrogen and helium isotopes in the energy range 10–50 MeV/n. Data of ^{3}He and ^{4}He were used to determine the ^{3}He/^{4}He ratio. For each event the deuterium-to-proton ratio was also estimated. This ratio, averaged over all events, is less than 3×10^{-5}.

1. Introduction

Indications that some of the ^{2}H created in solar flares can escape from the Sun into interplanetary space has been reported by Aglin et al. [1] and Aglin [2]. These works report the ^{2}H/^{1}H ratio measured with IMP-5 and IMP-6 instruments averaged over many flares. The value of the ratio was $(5.4\pm2.4)\times10^{-5}$ and $(1.3\pm0.3)\times10^{-4}$ respectively in 8–13 MeV/n energy range. This value is one order of magnitude higher than the upper limit typical for solar wind. Rothwell at al. [8] found an upper limit to the ^{2}H/^{1}H ratio equal to 1.4×10^{-5} at 2.4–23.0 MeV/n with S72-1 satellite over the polar regions during the solar active period from 30 October to 2 November 1972.

In a work by Mewaldt and Stone [6] an upper limit compatible with solar wind values was obtained by summing up the measurements over several flares

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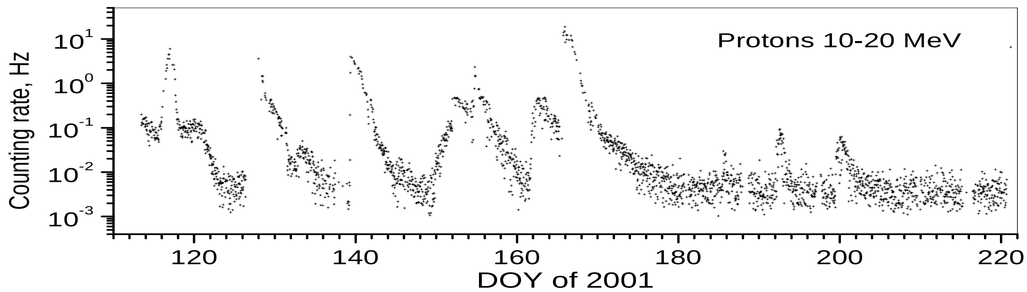

Fig. 1. Time profile of proton counting rate at L-shell> 6 between May 2001 and August 2001 measured by NINA-2.

observed aboard IMP-7 instrument. McGuire at al. [5] reported ^{2}H/^{1}H upper limits for 15 individual events measured with IMP-8. The limits are consistent with previous results ranging from 2×10^{-3} to $8\times\ 10^{-5}$, although the summed limits set by Mewaldt and Stone are lower. During Helios-1 observations of the 3 June 1982 and 21 June 1980 γ-ray/neutron events, upper limits of the ^{2}H/^{1}H ratio equal to 1.2×10^{-3} and 6×10^{-4} respectively were obtained in 4–42 MeV/n energy range [10].

The instrument NINA measured a ^{2}H/^{1}H ratio of $(3.4\pm1.4)\times10^{-5}$ in the energy range 10–14 MeV/n over a certain number of SPE events. One of observed events could probably have had this ratio equal to $(3.5\pm1.4)\times10^{-4}$, close to chromospheric values in flare regions [3]. The mission NINA-2 on board MITA satellite is the continuation of the NINA mission; this paper reports new measurements of light nuclei isotopes during Solar Particle Events with NINA-2 instrument.

2. The experiment

The NINA-2 instrument, described already in several works [3, 4], has mass resolution of 0.15 amu for light nuclei, thus giving the possibility to resolve H and He isotopes between 10 and 50 MeV/n. The instrument was placed in orbit by the Italian satellite MITA on 15 July 2000. The satellite had an almost circular polar orbit (inclination 87.3°) with altitude of about 450 km. Measurements were carried out in two different modes: zenith orientation and Sun pointing orientation.

3. Data analysis

The selection of solar particle events (SPE) was made by analyzing of proton count time profile in polar regions (L-shell>6, where the geomagnetic field does not affect solar particles with E>10 MeV/n). Figure 1 shows the count rate of protons with 10÷20 MeV in the period May 2001 – August 2001. The method of SPE events identification was the same as for NINA [3]. Table 1 shows the list of SPE events.

Table 1. $^3He/^4He$ and $^2H/^1H$ ratios in SPE events measured by NINA-2.

SEP events date	DOY	$^3He/^4He$	$^2H/^1H$
17 Oct. 2000	287	$< 3\times10^{-3}$	$<3\times10^{-4}$
8 Nov. 2000	313	$< 2\times10^{-3}$	$<1\times10^{-2}$
24 Nov. 2000	328	$< 1.2\times10^{-3}$	$<1\times10^{-4}$
28 Jan. 2001	28	$< 1\times10^{-2}$	$<3\times10^{-5}$
3 Apr. 2001	92	$< 1\times10^{-3}$	$<7\times10^{-3}$
10 Apr. 2001	100	$< 1\times10^{-3}$	$<1\times10^{-3}$
18 Apr 2001	108	$< 2\times10^{-3}$	$<1\times10^{-3}$
7 May 2001	127	$< 7\times10^{-3}$	$<3\times10^{-4}$
19 May 2001	139	$< 2\times10^{-2}$	$<5\times10^{-5}$
3 June 2001	154	$< 1.8\times10^{-2}$	$<1\times10^{-4}$
10 June 2001	161	$< 1.7\times10^{-2}$	$<3\times10^{-4}$
14 June 2001	165	$< 1.4\times10^{-2}$	$(4^{+3}_{-2})\times10^{-5}$
18 July 2001	199	$< 1.1\times10^{-2}$	$<2\times10^{-4}$
9 Aug. 2001	221	$< 1\times10^{-3}$	$<5\times10^{-5}$

Unfortunately the satellite Sun pointing orientation partially affected particle fluxes. It was measured indeed that particle fluxes in North and South poles were different when the satellite pointed the Sun. That was ascribed to the Earth that shadowed the instrument during part of the pole passages. For this reason we excluded data gathered during passages over south regions for isotope ratio analysis. However, SPE fluxes measured in North polar region are consistent with those obtained by other experiments; indeed Figure 2 shows the He energy spectra during 14 June 2001 SPE event measured by NINA-2 and SIS (on board ACE satellite [http://www.srl.caltech.edu/ACE/ASC/level2]) taken in similar periods.

To calculate the isotope ratios a Bayesian iterative procedure was applied to mass distributions, to take into account the response function of the instrument to isotopes. Parameters of these response functions were inferred from beam test data and GEANT simulations. Statistic errors and upper limits were determined by "Bootstrap sampling" method [4] with 0.95 confidence level.

Solar quiet background was estimated by the particle counting rate between 20 July and 7 August 2001 (see Figure 1). It was assumed no background variation during all period of measurements.

4. Results and Discussion

The $^2H/^1H$ ratios calculated after background subtraction are presented in Table 1. Summing up 10 events from 3 April 2001 to 8 August 2001 an upper limit equal to $5^{+30}_{-5} \times 10^{-6}$ was determined.

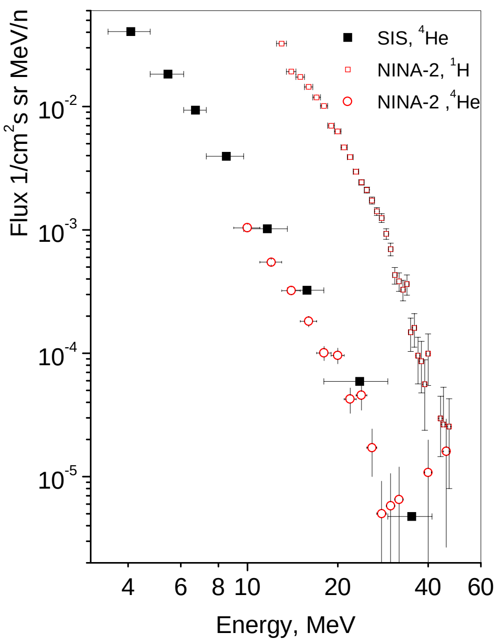

Fig. 2. Differential energy spectra of ^{1}H and ^{4}He measured by NINA-2 and SIS during 14 June 2001 SPE event.

The ^{3}He/^{4}He ratios are also presented in Table 1. No ^{3}He rich events were found. The 8 November 2000 and 3 April 2001 SPE events where the most intense in terms of light nuclei emission.

The measured ^{2}H/^{1}H ratio is in agreement with that obtained for NINA. This value is slightly less than that obtained by Aglin at. al [1, 2] with IMP-5 and IMP-6 instruments and greater than that of Mewaldt and Stone [6]. Mullan and Lynsky [7] suggest that ^{2}H/^{1}H could depend strongly on solar activity, so they conclude that Aglin at al. and Mewaldt and Stone results are not necessarily inconsistent.

NINA-2 mission covered the period of maximum solar activity in the 23th cycle, in conditions simliar to IMP-5 and IMP-6 measurements. Although the ratio obtained by NINA-2 is close to the value typical for the interstellar medium ($\sim 1.5 \times 10^{-5}$, see [7] for review) it is not possible to exclude that some deuterium created in a flare location could escape into interplanetary medium.

5. References

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