29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

ACE/NOZOMI Multispacecraft Observations of Solar Energetic Particles.

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We report multispacecraft measurements of solar energetic particle (SEP) events using Nozomi and ACE. During July 1998 to April 2002 while Nozomi was cruising toward Mars, both Nozomi and ACE observed many SEP events associated with coronal mass ejections (CMEs) and interplanetary shocks originating from different longitudes. These observations can reveal the longitudinal extent of CME-driven shocks and the accelerated particle populations. We use proton and electron data extending from ~40keV to ~1MeV measured with the EIS instruments on NOZOMI and the ULEIS and EPAM instruments on ACE. ACE and Nozomi have observed consistent number of proton events using daily average fluxes. In spite of their large longitudinal separation, 20 % of those events were simultaneously observed by ACE and NOZOMI. We also found more than 60 % of those events have been occurred after fast (>700km/s) halo CME which is significantly higher probability than chance coincidence. Three examples of individual event have been studied with hourly averaged data. On March 29, 2000, Nozomi observed CME which launched backside of Sun. On July 14, 2000 event and April 21, 2002 event, both of spacecrafts observed same SEP event with different longitudes which represent different intensity time profiles.

1. Introduction

Proton event associated with LDE flare often accompanies the CMEs. Thus this kind of solar energetic particle (SEP) thought be originated from the solar wind plasma and accelerated from the interplanetary CME shocks. The interplanetary shock associated with CMEs distribute with very large field so that the temporal variation of the SEP fluxes and spectra should be different according to the IMF which can simple define as a relative location between flare point and observer point [1][5]. More recent study from the measurement of Fe/O ratios, Cane et al. [2] suggested that two peaks of time-intensity profile appears during intense SEP events are due to CMEs and their accompanying flares which first peak related to flare and second related to CME-driven shock. Li and Zank [4] develop a model which examines particle acceleration and transport when both flares and CME-driven shocks are present. Time-intensity profiles for a pure shock case, a pure flare case and a shock-flare-mixed case are studied and found that the time intensity profile for the shock-flare-mixed case shows an initial rapid increase, owing to particles accelerated at the flare site and followed by a plateau similar to that of a pure shock case. On the other hand, Tylka et al. [7] gives alternative explanations of this Fe/O ratio with a seed population consisting of remnant flare material which enhanced Fe/O event were quasi-perpendicular shock and long-lasting events were quasi-parallel shock rather than source latitudinal distribution (See also [8]).

In this paper we report multispacecraft measurements of SEP events using ACE and NOZOMI during June 1999 to April 2002 while NOZOMI was cruising toward Mars.

2. Instruments and orbit

ACE was launched on August 1997 and injected into the Lagrangian point L1 on December 1997[6]. Operation has successfully continued since then. For this study, we used proton and electron data observed with EPAM and ULEIS instruments which has similar energy range with Nozomi/EIS. Nozomi was launched on July 1998 as a first Japanese mission of Mars orbiter. EIS (The Electron and Ion Spectrometer) is one of the plasma detectors on Nozomi which design to measure electrons, protons and the composition of heavy ions from ~40 keV to a few MeV [3].

Figure 1 shows the relative location of NOZOMI to Earth from June 20, 1999 to April 25, 2002 in Sun - Earth fixed coordinates. The stars with A, B and C indicate NOZOMI locations correspond to Figure 2 (Jul 14, 2000), Figure 3 (Mar 27, 2000) and Figure 4 (Apr 20, 2002), respectively.

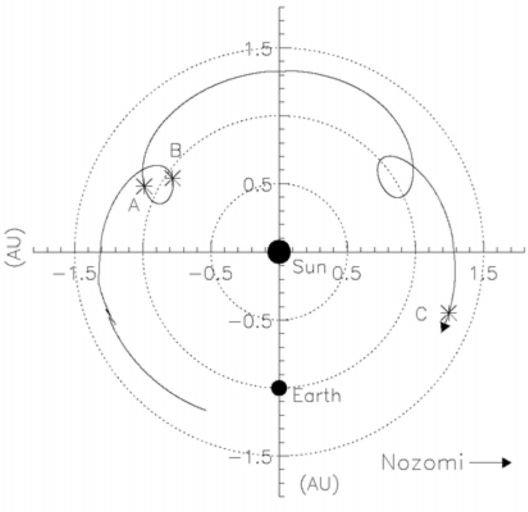

Figure 1. Relative orbit of NOZOMI in the period of June 20, 1999 to Apr 25, 2002. The curve with arrow shows NOZOMI relative trajectory in the Sun – Earth fixed coordinate. The stars with A, B and C indicate NOZOMI locations corresponding to Fig. 2(Jul 14, 2000), Fig. 3 (Mar 27, 2000) and Fig. 4 (Apr 20, 2002) respectively.

3. Observation

For the first step, we simply compare temporal variation of fluxes observed with ACE and NOZOMI in the period of June, 1999 to Apr, 2002. Due to relatively poor coverage of EIS observational live time, we used daily average fluxes. Note that even using daily average Nozomi only has 61% days of ACE. As figure 1 show, Nozomi was mostly far away from Earth which makes hard to determine related flares/CMEs from SEP event observed by Nozomi. For this reason, most of case we can not select events from other observations such as x-rays, CMEs or radio. Instead of selecting event based on those observations, we define "event" as itself as daily average intensities increased by ~2.5σ. With this simple definition, ACE and Nozomi observed 117 and 55 events respectively (here after ACE event and Nozomi event). 23 of ACE events out of 117 events were overlapped with Nozomi events.

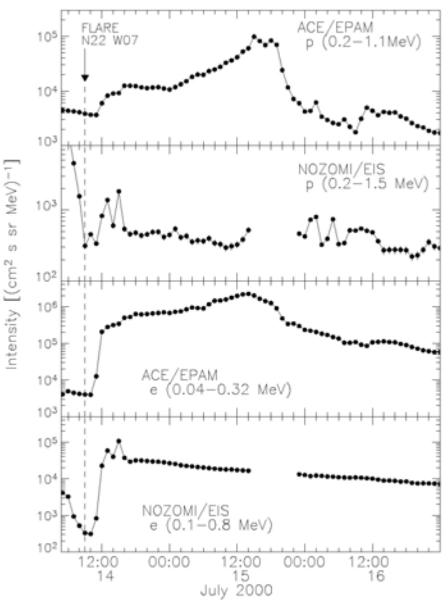

Figure 2. Intensity-Time profiles of proton and electron flux measure by EPAM and EIS from July 14, 2000 to July 16, 2000. Dashed line indicates X-flares at 1024UT on July 14, 2000.

Next, we used hourly average fluxes of ACE and Nozomi to examine more detail. Figure 2, 3 and 4 shows hourly averaged intensity time profiles of proton and electron observed with ACE and NOZOMI.

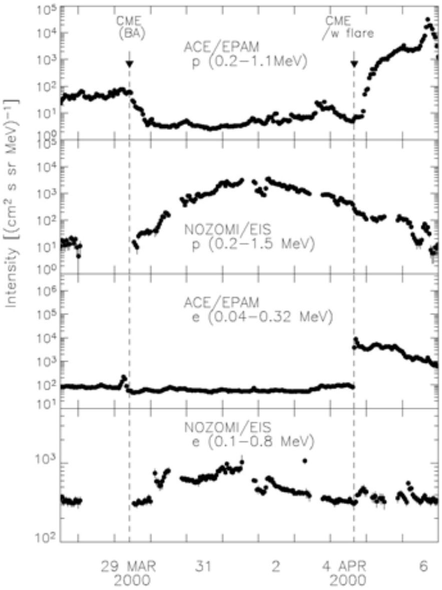

Figure 3. Intensity-time profiles same as Fig. 2 with period from March 27, 2000 to 6 Apr, 2000. Two dashed line represent CMEs onset 1054UT on March 29 and 1632UT on April 4.

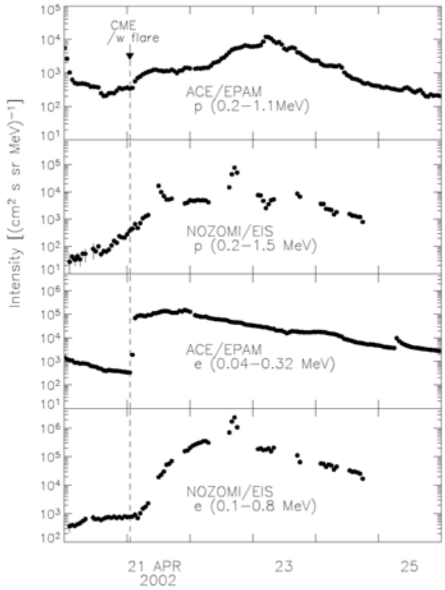

Figure 4. Intensity-time profiles same as Fig. 2 with period from April 20, 2002 to April 25, 2002. The dashed line represents Halo CME onset 0151UT on April 21, 2002.

Figure 2 shows intensity time profiles of proton and electron measure by EPAM and EIS while Bastille events. From top to bottom, each panel represents EPAM proton fluxes at 0.2 – 1.1 MeV, EIS proton fluxes at 0.2 – 1.5 MeV, EPAM electron fluxes at 0.04 – 0.32 MeV and EIS electron fluxes at 0.1 – 0.8 MeV. While this period GOES reports an X5.7 class flare event from AR9077 starting at 10:03 UT. This x-flare has shown as a dashed line in this figure. LASCO and EIT observed a full halo CME which first visible at 10:54 UT. Nozomi's longitudinal angle between ACE (here after ASN angle) was -116 degree (Nozomi was behind Earth) and distance from Sun was 1.1 AU.

Figure 3 shows the case which Nozomi observed SEP event but not at ACE and vice versa at the later part. Two dashed lines indicate onsets of halo CME at 10:54UT on March 29, 2000 and at 16:32UT on April 4, 2000 observed with LASCO and EIT. EIT images show that first CME (marked BA) was a back side event. Second halo CME was associated with C9.7 X-flare at N15W66. While this period, Nozomi was located at 1.0AU from Sun and -125 degree of ASN angle.

Figure 4 shows intensity time profile from April 20, 2002 to April 25, 2002. Dashed line indicate onset of partial halo CME at 01:51UT on April 21, 2002 observed with EIT and LASCO. GOES shows a long duration M1.5 class x-ray flare between 00:43-02:38 UT. While this period, Nozomi located at 1.3 AU from Sun and ASN angle was 90 degree (Nozomi was ahead of ACE). Nozomi proton flux was gradually

Table 1.

	ACE events	ACE evcnts /w CME	Nozomi events	Nozomi events /w CME	ACE + Nozomi events
Number of events	117	78 (67%)	55 (108)*	36 (66%)	23 (20%)

Number of events during June 1999 to April 2002 from daily average of proton flux observed with EPAM and EIS. See text for more detail.

* Number of events corrected with EIS observational live times.

increasing already before onset of CME probably due to another event.

4. Discussion and Summary

While ACE and Nozomi where nearly same distance from Sun (~1AU), even two spacecraft were located at different longitude, statically number of ACE and Nozomi events should be consistent. However the number of Nozomi events has only 47% of ACE events. This is related to our event selecting procedure which we need at least more the two adjacent days to determine event and only 51% day data are useable for this study. Comparing two groups of these event dates, in spite of their large longitudinal separation, 20 % of events were observed both by ACE and NOZOMI. This possibly suggests broad longitude distribution of these events. We also surveyed possible related CMEs of ACE and Nozomi event from LASCO catalog. As we are using daily average data at this point, events should related to a long duration event or very large size of impulsive event. To minimize candidate related solar activity, we restrict to use only halo CME and partial halo CME with faster than 700 km/s (liner fit value). We define related CME which occurred within -2 days of ACE or Nozomi events. We found 78 (67%) events out of 117 for ACE events and 36 (66%) events out of 55 for Nozomi events have possible related to halo CMEs. Surprisingly both observations has consistent ratio of related CMEs and this ratio is higher than chance coincidence ratio which is 47 ± 4%. Although with this simple definition, we might count wrong CMEs and we need better statistics and more individual events analysis to conclude. Results are summarized in Table 1.

Three examples of individual event have study with hourly averaged data. Taking account of SOHO CME observation, Nozomi has observed gradual increasing SEP event related to halo CME which launched backside of Sun on March 29, 2000. On July 14, 2000 event and April 21, 2002 event, both of spacecrafts observed same SEP event with different longitudes. Both of case proton events were not obvious as electron. On April 21, 2002 event, both of spacecraft observed electron flux was clearly correlated with this solar event and lead rapid increases of ACE fluxes while more rounded increases of Nozomi fluxes. On July 14, 2000 event has slightly different onset but both increase rapidly of electron flux while decay phase has different features as shown in Figure 2.

5. Acknowledgements

We thank the ACE EPAM, ULEIS, SWEPAM and MAG instrument team and the ACE Science Center for providing the ACE data. The CME catalog which we used in this study has generated and maintained by NASA and The Catholic University of America in cooperation with the Naval Research Laboratory. SOHO is a project of international cooperation between ESA and NASA. GOSE data are provided from National Geophysical Data Center.

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