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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, instruments on both spacecraft 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 instrument on NOZOMI and the ULEIS and EPAM instruments on ACE. ACE and Nozomi observed a consistent rate of proton events. In spite of their large longitudinal separation many events were simultaneously observed by ACE and NOZOMI. Four examples of individual events have been studied with hourly averaged data. On March 29, 2000, Nozomi observed an event following a CME on the backside of the Sun. In the July 14, 2000 and April 21, 2002 events, both spacecraft observed the same SEP event from different longitudes, resulting in different intensity time profiles.

1. Introduction

Gradual solar energetic particle (SEP) events are thought to originate from solar-wind plasma and suprathermal particles accelerated by interplanetary CME-driven shocks. The interplanetary shocks distribute particles over a broad range of longitudes so that the temporal variation of the SEP fluxes and spectra depend on the relative locations of the flare and observer [1][5]. In a recent study based on Fe/O measurements, Cane et al. [2] suggested that the occurrence of two peaks in the time-intensity profiles of some intense SEP events is due to a superposition of flare and shock acceleration in which the first peak is due to flare-accelerated particles and second is due to shock-accelerated particles. Li and Zank [4] developed 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 were studied and the time intensity profile for the shock-flare-mixed case showed an initial rapid increase, owing to particles accelerated at the flare site, followed by a plateau similar to that of a pure shock case. On the other hand, Tylka et al. [7] give an alternative explanation for the Fe/O behavior, in which Fe-rich events are accelerated at quasi-perpendicular shocks from a seed population of remnant flare material, while "normal" events are accelerated at quasi-parallel shocks from the solar wind (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 in 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 have similar energy ranges to Nozomi/EIS. Nozomi was launched on July 1998 as the first Japanese mission to Mars. EIS (The Electron and Ion Spectrometer) is one of the particle detectors on Nozomi which was designed to measure electrons, protons and the composition of heavy ions from ~40 keV to a few MeV [3].

Figure 1 shows the location of Nozomi relative to Earth, in Sun - Earth fixed coordinates, from June 20, 1999 to April 25, 2002.

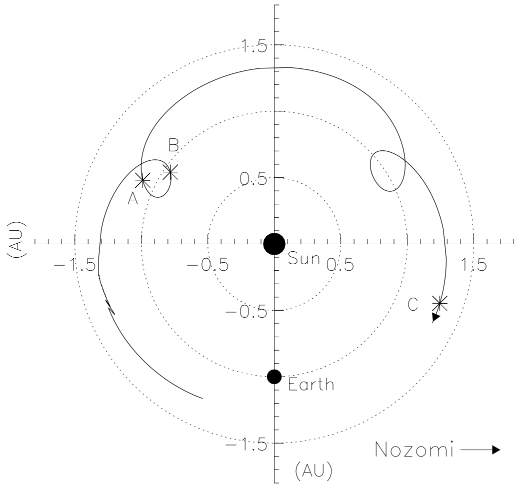

Figure 1. Relative orbit of Nozomi during the period from June 20, 1999 to April 25, 2002. The curve with an arrow shows the NOZOMI trajectory in Sun–Earth fixed coordinates. The stars marked A, B and C indicate the NOZOMI locations corresponding to Figure 2, Figure 3, and Figure 4, respectively.

3. Observations

As a first step, we compare the temporal variation of fluxes observed with ACE and NOZOMI in the period from June, 1999 to April, 2002. Due to the relatively poor coverage of EIS observations, we use daily average fluxes. Note that even using daily averages, Nozomi only has 61% of the coverage of ACE. If we simply select days with an average proton flux more than 1000 [cm^2 s sr MeV]$^{-1}$, ACE and Nozomi observed 123 and 67 days respectively (here after ACE event and Nozomi event). Twenty-two days of the 123 ACE events overlapped with Nozomi events. However this does not mean that all of these events occurred from same solar events. With this energy range not only SEP events but also interplanetary shock events may also count in these events.

Next, we use hourly average fluxes of ACE and Nozomi to examine events in more detail. Figure 2, 3 and 4 show hourly-averaged intensity-time profiles of protons and electrons observed with ACE and NOZOMI. Figure 2 shows intensity-time profiles of protons and electrons measured by EPAM and EIS during the Bastille Day event. From top to bottom, each panel represents EPAM proton fluxes at 0.19 – 1.05 MeV, EPAM electron fluxes at 0.038 – 0.315 MeV, EIS proton fluxes at 0.2 – 1.5 MeV, and EIS electron fluxes at 0.1 – 0.8 MeV.

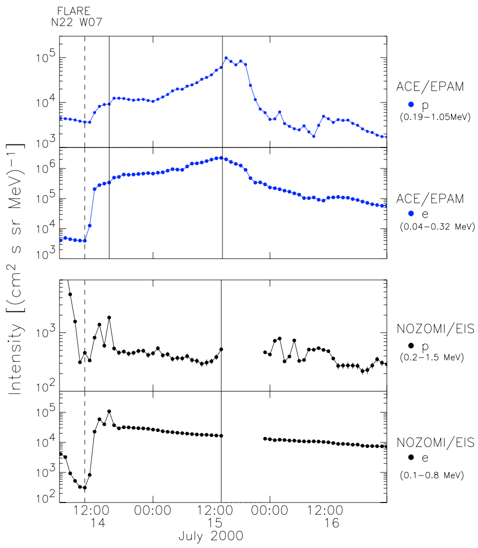

Figure 2. Intensity-time profiles of protons and electrons measured by EPAM and EIS from July 14, 2000 to July 16, 2000. Dashed line indicates an X-class flare at 1024UT on July 14. Solid lines indicate shock passages. The Nozomi shock could have had another origin.

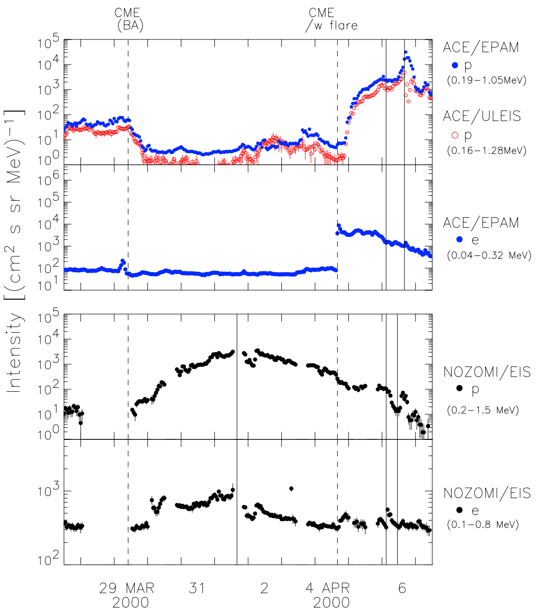

Figure 3. Intensity-time profiles (as in Fig. 2) for March 27, 2000 to April 6, 2000. The two dashed lines represent CMEs with onsets at 1054UT on March 29 and 1632UT on April 4. ACE/ULEIS proton time profile is also shown.

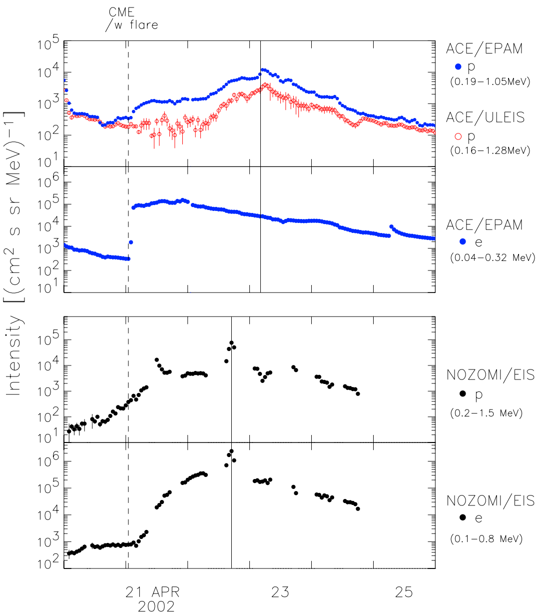

Figure 4. Intensity-time profiles (as in Fig. 2) from April 20, 2002 to April 25, 2002. The dashed line represents a Halo CME with an onset at 0151UT on April 21, 2002. The ACE/ULEIS proton time profile is also shown.

During this period GOES reported an X5.7 class flares from AR9077 (N22W07) starting at 10:03 UT. This flare is shown as a dashed line in this figure. LASCO and EIT observed a full halo CME which was first visible at 10:54 UT. Nozomi's longitudinal angle with ACE (here after ASN angle) was –116° (Nozomi was behind Earth at 1.1 AU from the Sun). The vertical solid lines indicate the times of shock passages measured by MAG and SWEPAM for ACE and MGF (Magnetic Field Measurement) for Nozomi. Occasionally, the two spacecraft appears to observe the shock simultaneously that they have same origin.

Figure 3 shows a period in which Nozomi observed an SEP event but not ACE, and vice versa during the latter part of the period. In this figure, ACE/ULEIS proton fluxes at 0.160 – 1.280 MeV are also shown in the top panel. Two dashed lines indicate a halo CME at 10:54UT on March 29, 2000 and 16:32UT on April

Table 1.

Date / Location *	Flare location	X flare/onset	CME/ Appearance Time**	ASN / Distance (AU)	Flare locatoion from Nozomi ***	ACE+Nozomi Particle Event?
July 14, 2000 / A	N22W07	X5.7/10:03	Halo/10:54	-116°/1.1	W123	Yes
Mar. 29, 2000 / B	Backside	-	Halo/10:54	-125°/1.0	East	Nozomi
April 4, 2000 / B	N12W66	C9.7/15:12	Halo/16:32	-124°/0.9	E170	ACE + ?
April 21, 2002/ C	S14W84	X1.5/00:43	Halo/01:27	90°/1.3	E06	Yes

* Relative Nozomi location corresponds to figure 1.
** First time appearance on LASCO C2.
*** Flare longitudinal location seen from Nozomi.

4, 2000, as observed with LASCO and EIT. EIT images show that the first CME (marked BA) was a backside event. No associated flare was reported during the first CME, while the second halo CME was associated with C9.7 x-ray flares at N15W66. During this period, Nozomi was located at ~1.0AU from Sun and at ~ -125° ASN angle.

Figure 4 shows an intensity time profile from April 20, 2002 to April 25, 2002. The dashed line indicates a halo CME at 01:27UT on April 21, 2002 observed with EIT and LASCO. GOES reports a long duration X1.5 x-ray flare beginning at 00:43UT and located at S14W84. During this period, Nozomi was located at 1.3 AU from the Sun with an ASN angle of 90°. The Nozomi proton fluxes were gradually increasing before the CME onset, probably due to another event.

4. Discussion and Summary

Four examples of individual events have been studied with hourly-averaged data. Associated flares/CMEs are summarized in Table 1. In the July 14, 2000 and April 21, 2002 events, both spacecraft observed the same SEP event from different longitudes. In both cases the proton events were not as well defined as the electron events. In the July 14, 2000 event the electron intensity increased rapidly at both spacecraft. During the next 24 hours the both the electron and proton intensities at ACE gradually increased as the shock approached. Although, Nozomi also observed a shock with MGF, there was no clear evidence in the particle data. In the April 21, 2002 event, both spacecraft observed electron increases clearly correlated with this solar event. Considering the spacecraft locations, rapid increases at ACE and more rounded increases at Nozomi were consistent with previous observations. The shock reached Nozomi first, as expected.

Nozomi observed a gradually increasing SEP event related to a halo CME launched on March 29, 2000 from the backside of Sun (based on SOHO CME observations). Viewed from Nozomi, the flare location was somewhere on the East side, which explains why the SEPs gradually increased as the shock approached.

In the April 4, 2000 event two similar shocks were observed at both spacecraft. However, Nozomi was ~180° from the flare location, which suggests some kind of lateral transport mechanism may apply if the ACE and Nozomi shocks in fact have the same origin. Better event statistics and more analysis of individual events are needed before drawing a conclusion.

5. Acknowledgements

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