Energetic Particle Observations by the Cassini Spacecraft During its Heliospheric Cruise to Saturn

D. Lario[1], S. Livi[1], R. B. Decker[1], E. C. Roelof[1], S. M. Krimigis[1], and M. K. Dougherty[2]
(1) Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, U.S.A.
(2) Blackett Laboratory, Imperial College, London, U.K.

Abstract

We present energetic particle observations performed by the Cassini spacecraft during its heliospheric cruise to Saturn. We cover three years of data (2000-2002) during the maximum of the solar cycle 23. Cassini's heliocentric radial distance ranged from 2.5 to 8.0 AU. Energetic particle intensity enhancements at these distances are associated with either Solar Energetic Particle (SEP) events or Corotating Interaction Regions (CIRs). High-energy (>25 MeV) ion intensity increases are associated with intense SEP events. The largest low-energy (<8 MeV) ion intensities occur at the passage of transient interplanetary shocks associated with SEP events. Comparison with energetic particle data at 1 AU shows that, in general, intense SEP events near Earth are also observed at Cassini. However, when a new injection of SEPs occurs after a period of intense solar activity, it may produce a new SEP event at 1 AU but not at the larger heliocentric radial distances where Cassini is. Recurrent CIR events are also observed during solar maximum. In particular, we study the recurrence of four CIR events first seen near Earth and later at Cassini (at ∼7 AU).

1. Observations

The Low-Energy Magnetospheric Measurement System (LEMMS) onboard the Cassini spacecraft measures ions and electrons in the range of a few tens of keV to several MeV [1]. Fig. 1 shows data from selected rate channels of LEMMS for a three year period (2000-2002) of the Cassini interplanetary (IP) cruise. The heliocentric radial distance of Cassini is indicated on top of Fig. 1. The gray bar indicates the period of the Jupiter flyby; these data have been presented elsewhere, e.g. [2]. Vertical arrows indicate low-energy (<800 keV) ion increases associated with the passage of IP shocks (identified using magnetic field data, although this figure does not constitute a comprehensive list of shocks observed by Cassini during this period). The largest low-energy (<800 keV) ion intensities, as well as low-energy (43-57 keV) electron intensities, are observed in association with IP shocks. We emphasize the high intensities reached on days 342 of 2000,

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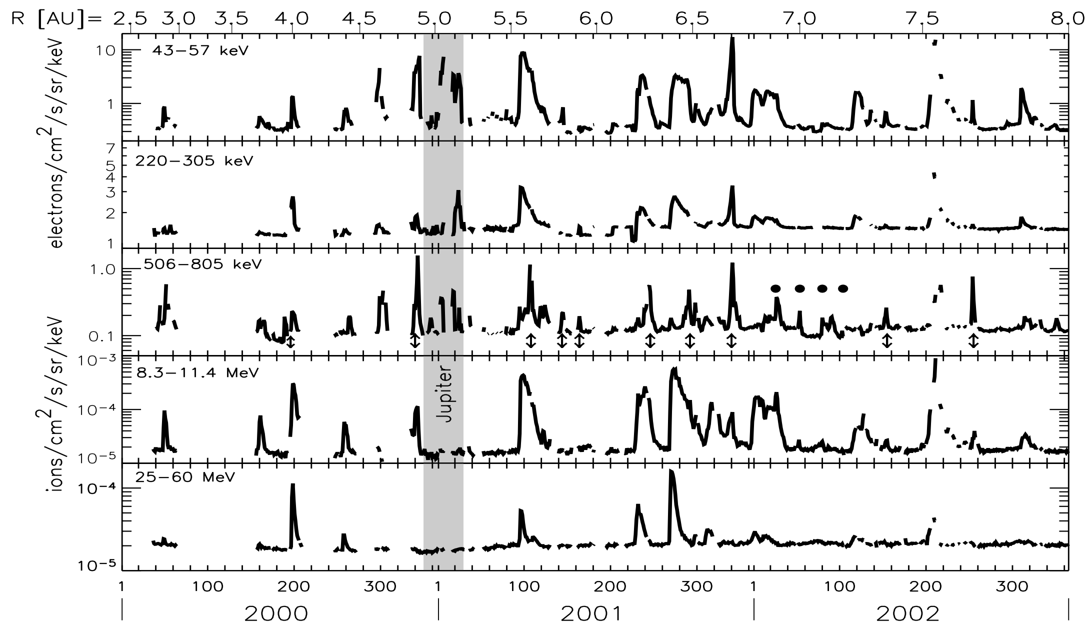

Fig. 1. 1-day averaged electron (two top panels) and ion (three bottom panels) intensities as measured by LEMMS on board Cassini [1]. Black dots indicate the sequence of four CIRs shown in Fig. 3. Vertical arrows indicate intensity enhancements associated with IP shocks (see text for details).

days 107 and 341 of 2001, and day 254 of 2002.

Fig. 2 compares high-energy ion intensities as measured by GOES-8 at 1 AU and by Cassini at 2.5-8.0 AU. The most intense SEP events (identified at the bottom of Fig. 2) are usually observed at both spacecraft. The exceptions are the two large SEP events in November 2000 (because of a data gap at Cassini) and the two large SEP events in November 2001 (especially the second one) that did not produce any intensity increase at Cassini. Lario et al. [3] show that the intensities of these large SEP events at Cassini are reduced because of the heliospheric energetic particle transport conditions. Previous solar events may generate transient plasma flows in the IP medium that are effective barriers to the propagation of SEPs to Cassini. For example, prior to the events in November 2001, numerous SEP events were observed at 1 AU (Fig. 2), suggesting that several fast transient plasma flows propagating between the Sun and Cassini impeded the arrival of SEPs at Cassini (details can be found in [3]).

Fortuitously, it was possible to observe a sequence of CIR events in the ecliptic plane during solar maximum. Fig. 3 shows a sequence of four CIRs observed first by the ACE spacecraft at 1 AU and later by Cassini. The association between both sets of CIRs is based on both (i) the presence of an equatorial hole on the Sun and (ii) the corotation delay of the solar wind streams between both spacecraft. The dynamic character of the coronal hole and of the interaction between the solar wind streams introduces a variation in the expected arrival

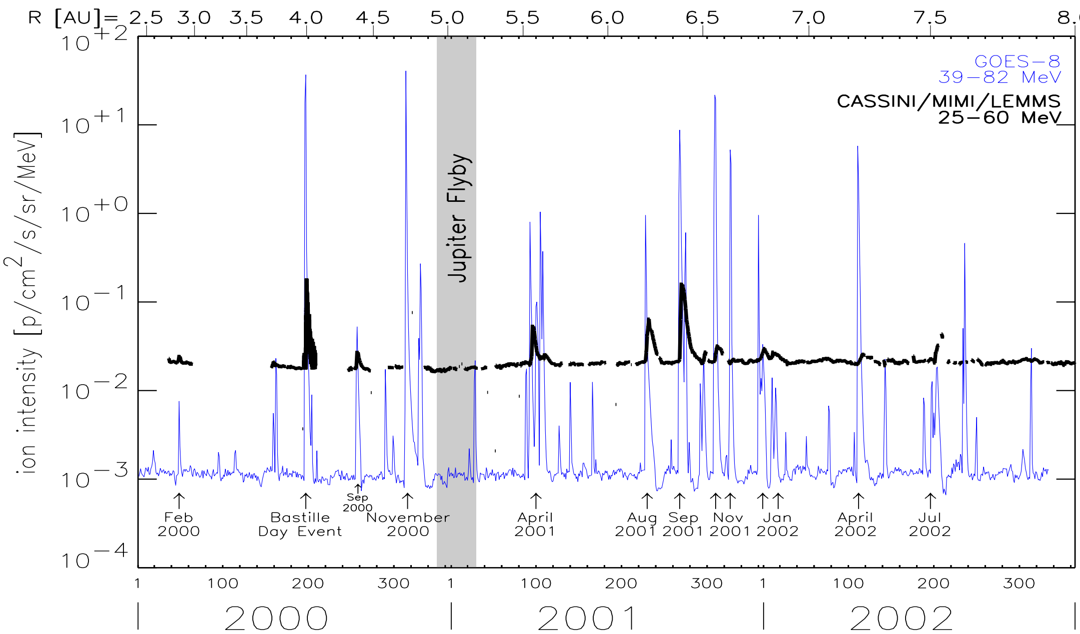

Fig. 2. 1-day averaged high-energy ion intensities as measured by LEMMS (thick trace) and GOES-8 (thin trace).

time of the CIRs at Cassini (indicated by the inclined solid lines in Fig. 3). The occurrence of several transient events (identified by T in Fig. 3) obscured the contribution of CIRs to the energetic particle population at 1 AU. At large heliocentric distances, where SEP intensities decrease, the low-energy (<5 MeV) ion intensity enhancements due to local effects of the CIRs are clearly observed.

2. Conclusions

From the analysis of the Cassini energetic particle data and their comparison with 1 AU observations we draw the following conclusions: (1) Sequences of SEP events at 1 AU are generally observed as a single merged SEP event at Cassini (e.g., April 2001). (2) The most intense SEP events are usually observed by both the near-Earth spacecraft and Cassini, regardless of their longitudinal separation. (3) However, in specific events, Cassini may remain shielded from new SEP injections, depending on the previous level of solar activity [3]. (4) High-energy (>25 MeV) ion intensity increases at Cassini are exclusively associated with intense SEP events. (5) Energetic storm particle events associated with the passage of IP shocks is the predominant type of low-energy (<1 MeV) ion event at heliocentric distances between 2.5 and 8.0 AU. (6) During solar maximum, CIR events are more clearly identifiable at Cassini's larger heliocentric distances than at 1 AU.

3. References

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3. Lario D. et al. 2003, JGR, submitted

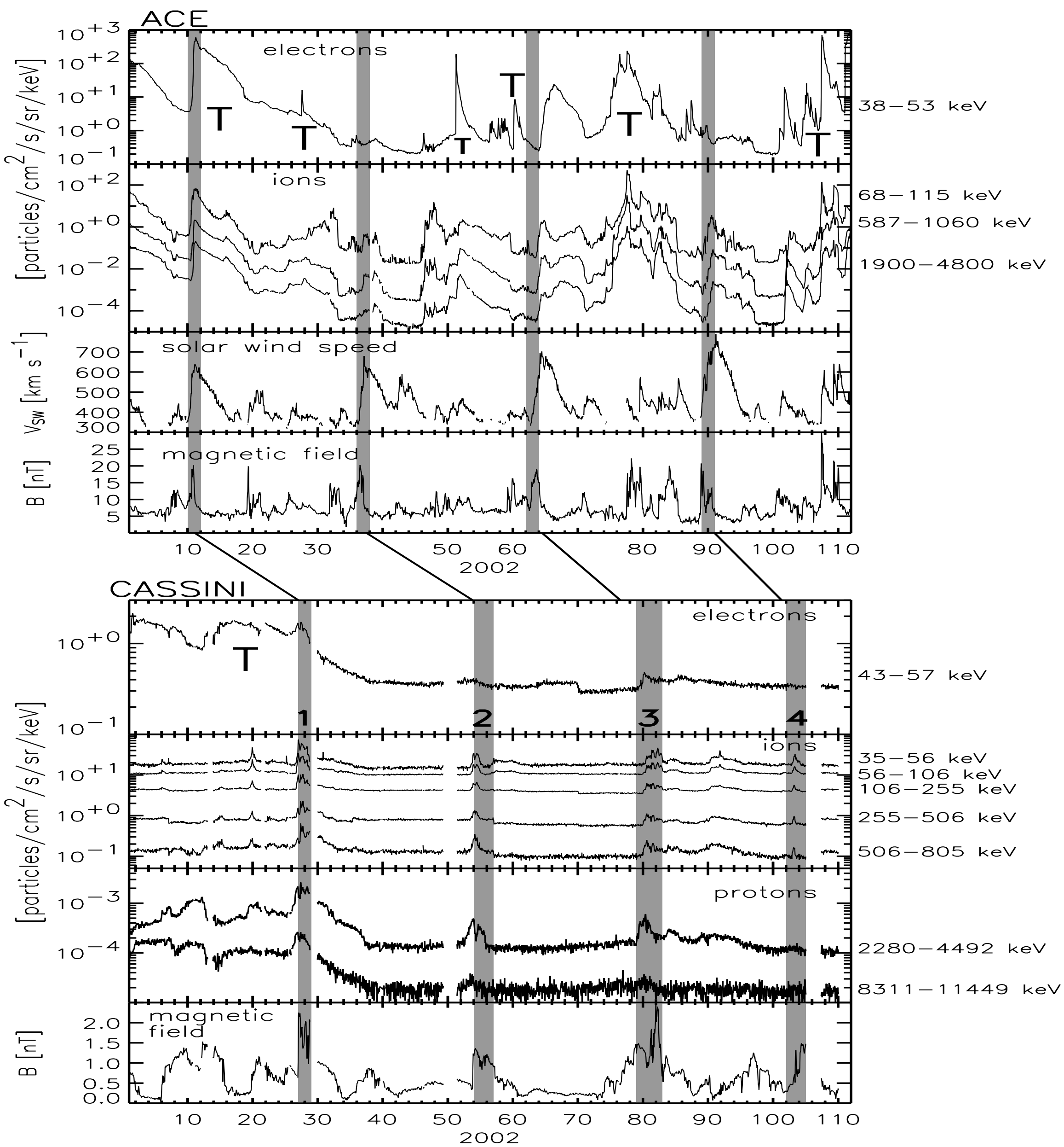

Fig. 3. Sequence of four CIR events (vertical gray bars) observed first at ACE (top panel) and later at Cassini (bottom panel). ACE data have been obtained from the ACE Science Center. During this period, Cassini moved from 6.81 to 7.21 AU in heliocentric radial distance and the longitudinal separation between Earth and Cassini ranged from 20° to 123°.