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ScienceDirect
Advances in Space Research 52 (2013) 2102–2111
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

# Solar energetic particle events during the rise phases of solar cycles 23 and 24

R. Chandra [a,*], N. Gopalswamy [b], P. Mäkelä [b], H. Xie [b], S. Yashiro [b], S. Akiyama [b], W. Uddin [c], A.K. Srivastava [c], N.C. Joshi [c], R. Jain [d], A.K. Awasthi [d], P.K. Manoharan [e], K. Mahalakshmi [e], V.C. Dwivedi [e], D.P. Choudhary [f], N.V. Nitta [g]

[a] Department of Physics, DSB Campus, Kumaun University, Nainital 263 002, India
[b] NASA Goddard Space Flight Center, Greenbelt, MD 20771-0001, USA
[c] ARIES, Manora Peak, Nainital 263 129, India
[d] Physical Research Laboratory, Ahmedabad 380 009, India
[e] TIFR/NCRA Radio Astronomy Center, Ooty 643 001, India
[f] Department of Physics & Astronomy, California State University, Northridge, CA 91330-8268, USA
[g] Lockheed Martin Solar and Astrophysical Laboratory, A021S, Hanover Street, Palo Alto, CA 94304, USA

Received 25 November 2012; received in revised form 3 September 2013; accepted 5 September 2013
Available online 12 September 2013

**Abstract**

We present a comparative study of the properties of coronal mass ejections (CMEs) and flares associated with the solar energetic particle (SEP) events in the rising phases of solar cycles (SC) 23 (1996–1998) (22 events) and 24 (2009–2011) (20 events), which are associated with type II radio bursts. Based on the SEP intensity, we divided the events into three categories, i.e. weak (intensity < 1 pfu), minor (1 pfu < intensity < 10 pfu) and major (intensity ⩾ 10 pfu) events. We used the GOES data for the minor and major SEP events and SOHO/ERNE data for the weak SEP event. We examine the correlation of SEP intensity with flare size and CME properties. We find that most of the major SEP events are associated with halo or partial halo CMEs originating close to the sun center and western-hemisphere. The fraction of halo CMEs in SC 24 is larger than the SC 23. For the minor SEP events one event in SC23 and one event in SC24 have widths < 120° and all other events are associated with halo or partial halo CMEs as in the case of major SEP events. In case of weak SEP events, majority (more than 60%) of events are associated with CME width < 120°. For both the SC the average CMEs speeds are similar. For major SEP events, average CME speeds are higher in comparison to minor and weak events. The SEP event intensity and GOES X-ray flare size are poorly correlated. During the rise phase of solar cycle 23 and 24, we find north–south asymmetry in the SEP event source locations: in cycle 23 most sources are located in the south, whereas during cycle 24 most sources are located in the north. **This result is consistent with the asymmetry found with sunspot area and intense flares.**


*Keywords:* Solar energetic particles; Type II radio bursts; Coronal mass ejections; Flares

## 1. Introduction

One of the most important and interesting aspects of a solar eruption is the acceleration of solar energetic particles (SEPs). It is believed that SEPs are accelerated at the shock ahead of coronal mass ejections (CMEs) (Kahler et al., 1978) or at the magnetic reconnection regions associated with solar flares (Mason et al., 1999). SEP events due to CME-driven shocks are large and gradual (long duration) in nature (Reames, 1999). Solar type -II radio bursts are also due to shocks from a solar eruption. Therefore, observations of type II bursts give information on shock associated SEPs. On the contrary, SEP events produced by the flare reconnection process are impulsive and short-lived in nature (Cane et al., 1986; Reames, 1999; Laurenza

* Corresponding author. Tel./fax: +91 5942 237450.
*E-mail address:* rchandra.ntl@gmail.com (R. Chandra).

0273-1177/$36.00 © 2013 COSPAR. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.asr.2013.09.006

et al., 2009; Cane et al., 2006; Bhatt et al., 2013). Both the shock and flare are expected to occur during energetic solar eruptions. Therefore, it might be possible that the observed SEPs are due to the combined effects of these two processes. However, there are examples in the literature where there was SEP event but no type II radio burst (Gopalswamy et al., 2004). Such events can be safely attributed solely to flare acceleration, happening low in the corona. CMEs associated with SEPs generally originate from solar active regions (Gopalswamy et al., 2010a). However, there are examples of CMEs associated with quiescent filament eruption (Kahler et al., 1986; Vršnak et al., 2003; Titov et al., 2012; Schmieder and Aulanier, 2012). Active regions can store and release vast amounts of magnetic energy. Due to the enhanced solar activity during the solar maximum phase, most of the SEP events occur in this phase, which makes it difficult sometimes to identify the source region of CMEs (for example Chandra et al. (2010)). In the rise phase of the solar cycle, SEP events are less frequent, thus providing a better opportunity to study the SEP events including the detection of their source region.

If the CMEs are faster, they drive stronger shocks, so there should be good correlation between CME speed and SEP events intensity. Many studies have shown good correlation between the SEP intensity and CME speed, but the correlation is not tight. On the other hand, the correlation between SEPs intensity and flare size is generally poor (Gopalswamy et al., 2003, 2004). Gopalswamy et al.

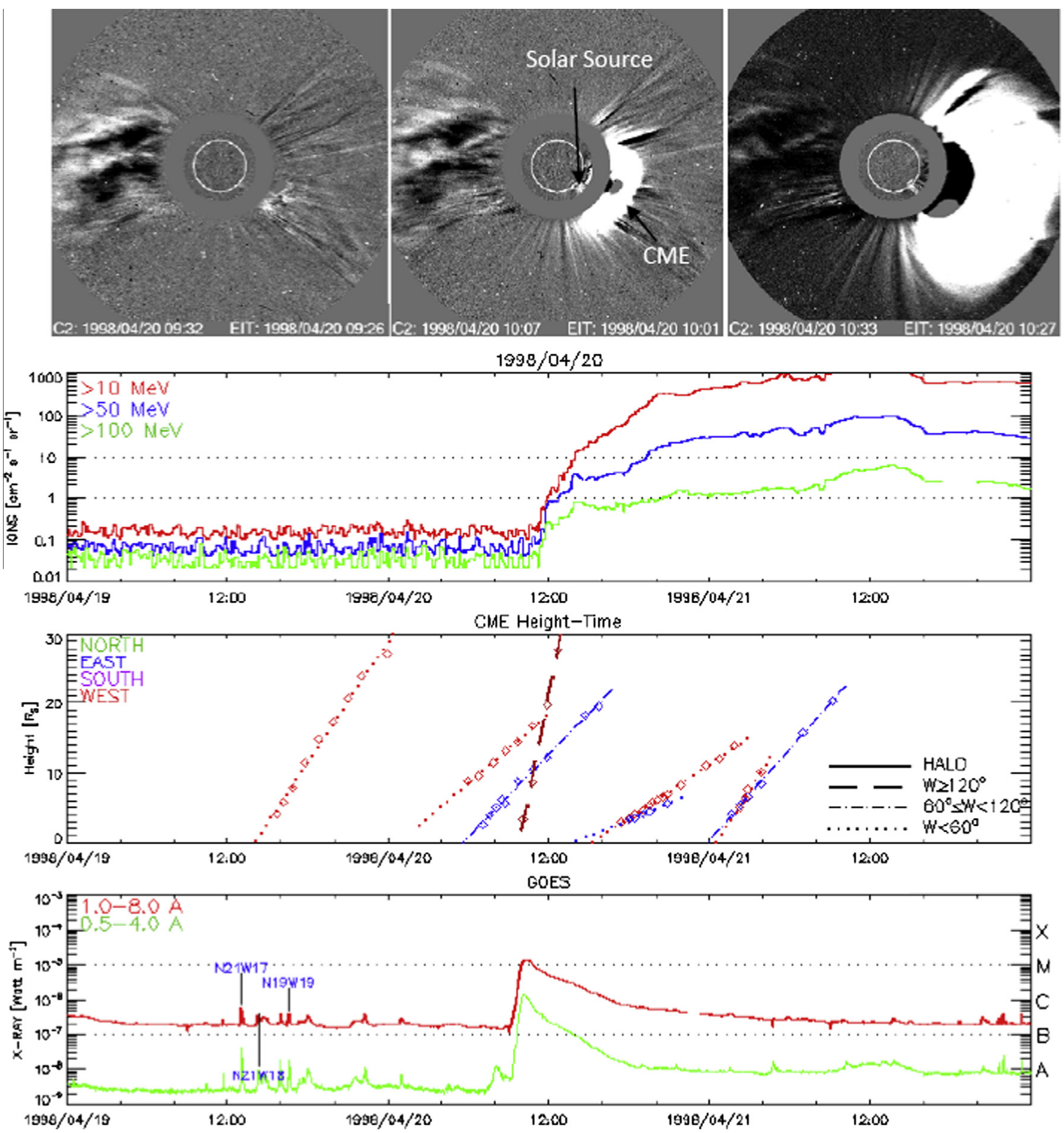


Fig. 1. An example of major SEP event and its source region on 20 April, 1998: Three snapshots of the CME that produced the SEP event (top panel), the time variation of SEP intensity in three energy channels (upper middle panel), the CME height-time plot of the CME (lower middle panel), the soft X-ray flare light curves in the two energy channels (bottom panel).