Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Characteristics of Solar Proton Events Observed Near Earth and Stellar Activity Variations

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Abstract. We could identify three categories of solar proton events (SPE) with distinct solar origin from an analysis of direct and indirect observations during the years 1561-2016 CE spanning 42 sunspot cycles. They are (i) 10 MeV SPE whose number of occurrences closely follow the sunspot cycles (ii) 30 MeV SPE which show secular changes with peaks near Gleissberg solar cycle minima and inferred to be associated with distinct enhancements in the efficiency of the solar dynamo and (iii) those associated with Impulsive and irregular solar activity changes such as the Carrington event of September 1859. The relevance of above results for stars exhibiting cyclic and irregular activity changes will be also discussed.

Keywords. Solar proton events, sunspot cycles, solar dynamo, Carrington event, stellar activity

1. Introduction

Solar proton events (SPE) arises due to transient phenomena in the solar atmosphere and influeces our space weather. In this paper,we have studied three types of SPE of distinct solar origin using direct and indirect solar observations for the past 42 sunspot cycles. The relevance of these results to cyclic and irregular stellar activity changes will be also discussed.

2. Results and Discussions

2.1. *Sunspot cycle variations of 10 MeV SPE*

The annual number(N) of 10 MeV SPE observed by satellites near earth (`www.ftp.swpc.noaa.gov`, `www.omniweb.gsfc.nasa.gov`) follows the sunspot activity variations. We could find a linear regression relation between annual mean International sunspot number (Rs) and number of occurrences (N) of 10 MeV SPE:

$$N = 0.0181Rs + 1.139 \quad (R^2 = 0.508) \tag{2.1}$$

2.2. *Secular changes in 30 MeV solar proton events and efficiency of the solar dynamo*

In the pre-satellite era nitrate measurements in polar ice helps to identify large solar proton events ($E > 30$ MeV and fluence $F >= 2 \times 10^9$ cm^{-1}) and such an inference is available for the period 1561–1950 CE (McCracken *et al.* 2001a). The number of such events (Np) and their culmulative fluence (Fc) for the sunspot cycles −17 to 24 (Smart *et al.* 2008) is shown in Fig. 1. We could find distinct enhancements in Np and Fc during the sunspot cycles −13 (1598−1609 CE), −4 (1698−1712 CE), 13 (1889-1901 CE) and

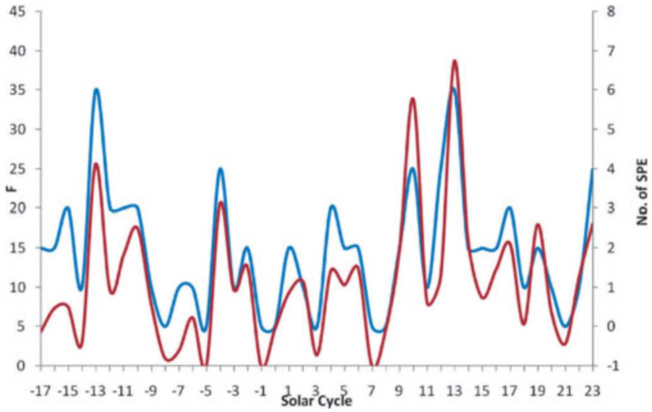

Figure 1. Variations of the cumulative fluence (red) and number of 30 MeV large proton events (blue) during the sunspot cycles −17 to 23.

23 (1986–2007) which occurs near Gleissberg solar cycle minima. (McCracken *et al.* 2001b). These enhancements can be inferred to be associated with secular changes in the efficiency of the solar dynamo as explained by Girish & Gopkumar (2010).

2.3. *Irregular super-transient event occurrences*

The SPE associated with the Carrington event of September 1859 is inferred to possess the largest fluence for any 30 MeV solar proton till known. This super transient event is identified to be an impulsive solar activity enhancement event and of irregular nature and not possibly connected with any periodic change in sunspot activity.

2.4. *Associations with stellar activity changes*

Several G type stars showing cyclic activity changes (period varying between 7–21 years) are inferred to have higher chromospheric activity and faster equatorial rotation compared to our Sun (Olah *et al.* 2016). These stars are likely to be associated with stellar proton events whose number varying closely with the cyclic stellar activity changes with energy proportional to the S index of these stars. Flare activity in M stars with exoplanets like the Proxima Centauri (Davenport *et al.* 2016) can be classified in the cateogory of impulsive and irregular stellar activity. For such stars super-transient events like super stellar flares are more probable to occur. These impulsive stellar activity changes will be accompanied by large fluence stellar proton events which will be more hazardous than the Carrington solar event of 1859 in the space weather perspective.

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