FREQUENCY DISTRIBUTIONS OF SOLAR FLARES

A. VERONIG, M. TEMMER and A. HANSLEMEIER

Institute for Geophysics, Astrophysics and Meteorology,
University of Graz, Universitätsplatz 5, A-8010 Graz, Austria

UDC 523.985.3-735
Conference paper

Abstract. Flare frequency distributions as function of the soft X-ray peak flux and fluence are investigated. We analyse GOES 1–8 Å data for the period 1986–2000. The results are discussed with respect to avalanche flare models and the hypothesis of coronal heating by nanoflares.

Key words: Sun - flares - self-organized criticality - coronal heating

1. Introduction

It has been shown in various studies that the frequency distributions of solar flare parameters are well defined power-laws (cf. Crosby et al., 1993; Aschwanden et al., 1998). Lu and Hamilton (1991) were the first to propose an avalanche model of solar flares, relating the power-law distributions to the scale-invariant properties of a self-organized system in a critical state. The actual value of the power-law index $\alpha$ describing flare energy distributions can be applied to test Parker’s hypothesis of heating the corona by nanoflares (Parker, 1988).

2. Data Set

We utilize soft X-ray (SXR) data from the Geostationary Operational Environmental Satellites (GOES) for the period 1986–2000. The 1-min averaged GOES data measured in the 1 8 Å wavelength band are used. We analyse soft X-ray peak fluxes and fluences, i.e. the flux
Figure 1: Frequency distributions as function of the peak flux calculated separately for periods of minimum and maximum activity of solar cycle 22 (left) and solar cycle 23 (right). Times of minimum activity are represented by full lines, times of maximum activity by dashed-dotted lines.

integrated over the event duration, without background subtraction. For the period 1997-2000, also background subtracted data are analysed. For background subtraction the flux just before the flare start is applied (see also Veronig et al., 2002).

3. Results

Figure 1 shows the frequency distributions of flare peak fluxes (not background subtracted) separately for periods of minimum and maximum solar activity. The left panel shows the distributions for solar cycle 22 (derived from the years 1986 and 1989), the right panel for the current cycle 23 (1996/2000). During times of maximum solar activity the power-law extends to larger peak fluxes due to the enhanced occurrence of intense flares. During minimum activity the power-law behaviour ranges to smaller peak fluxes, since also less intense flares can be detected. This is evidence that the turn-over of the power-law distribution is caused by the sensitivity of the observations, and the power-law behavior is expected to extend to even smaller sizes.

However, the slope of the distribution, i.e. the power-law index α, does not reveal any remarkable change in the course of the solar cycle. All distributions can be described by $\alpha \approx 2$. Since the avalanche size
distribution is insensitive to much of the microphysics, from flare models invoking self-organized criticality it is predicted that the power-law distributions do not change over the solar cycle (see, e.g., Lu and Hamilton 1991; Lu et al. 1993).

In Figure 2 we show the distribution of the SXR peak flux and SXR fluence after background subtraction, considering the period 1997–2000. Both distributions are described by a similar power-law index, $\alpha = 1.98 \pm 0.08$ and $\alpha = 1.89 \pm 0.10$, respectively.

4. Discussion and Conclusions

The actual value of the power-law index $\alpha$ is relevant for Parker’s idea of heating the corona by numerous small-scale magnetic reconnection events extending below the observational limit, i.e. nanoflares (Parker, 1988). Hudson (1991) calculated that if the power needed to heat the corona is generated by flare-like events of different sizes, then the total power, $P$, in the distribution of event rates per unit area is equal to the integral of event energies, $E$, times their frequency of occurrence per unit area and per unit time, $dN/dE$. Let $E_{\text{min}}$ and $E_{\text{max}}$ denote the energies of the smallest and largest events, respectively. Then the
total power $P$ per unit area can be expressed as:

$$P = \int_{E_{\text{min}}}^{E_{\text{max}}} \frac{dN}{dE} E \, dE . \quad (1)$$

If the frequency of events as function of energy follows a power-law of the form $\frac{dN}{dE} = A \, E^{-\alpha}$, the total power $P$ gives:

$$P = \frac{A}{(2 - \alpha)} \left( E_{\text{max}}^{2-\alpha} - E_{\text{min}}^{2-\alpha} \right) . \quad (2)$$

Assuming that $E_{\text{max}} \gg E_{\text{min}}$ and $\alpha < 2$ yields

$$P \approx \frac{A}{(2 - \alpha)} E_{\text{max}}^{2-\alpha} , \quad (3)$$

implying that events with large energies provide the dominant contribution to the heating. Otherwise, if $\alpha > 2$, then

$$P \approx \frac{A}{(\alpha - 2)} E_{\text{min}}^{2-\alpha} . \quad (4)$$

In this case, the more numerous small-scale events dominate the total power in the distribution. Thus, if nanoflares are to explain the steady energy dissipation required for coronal heating, it is necessary to have a power-law index $\alpha > 2$ (see Hudson, 1991; Parnell and Jupp, 2000).

The flare energy is not an observable quantity, and in general one has to be cautious in relating the frequency distributions of observed parameters to those of flare energies. However, under the assumption that the SXR fluence is proportional to the total radiated flare energy, the power-law index of the fluence distribution (after background subtraction) is also representative of the energy distribution. On the other hand, in the frame of the chromospheric evaporation model of flares, the SXR peak flux is linked to the accumulated energy deposited by accelerated electrons. Thus, the power-law index of the SXR peak flux distribution can also be considered as representative of a flare energy distribution. Indeed, both distributions, i.e. SXR peak flux and SXR fluence, give quite similar power-law indices. However, since the derived power-law index is close to the critical value of 2, the results are ambiguous with respect to the possibility of coronal heating by nanoflares.
Acknowledgements

This work was performed under grant P13655 of the Austrian Fonds zur Förderung der wissenschaftlichen Forschung (FWF).

References

RASPODJELE UČESTALOSTI SUNČEVIH BLJESKOVA

A. VERONIG, M. TEMMER i A. HANSLMEIER

Institute for Geophysics, Astrophysics and Meteorology,
University of Graz, Universitätsplatz 5, A-8010 Graz, Austria

UDK 523.985.3-735
Izlaganje sa znanstvenog skupa

Sažetak. Istražuju se raspodjele učestalosti bljeskova u ovisnosti o maksimalnom toku i ukupnom protoku mekih rendgenskih zraka. Analiziraju se podaci prikupljeni satelitima GOES u području 1–8 Å za razdoblje od 1986.–2000. Dobiveni rezultati diskutiraju se s obzirom na posebne modele bljeskova te hipotezu zagrijavanja korone nanobljeskovima.

Ključne riječi: Sunce - bljeskovi - samoorganizirana kritičnost - zagrijavanje korone