SOLAR AND STELLAR FLARES

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ABSTRACT. This review concentrates on some selected topics concerning the release of magnetic energy and associated phenomena in flares. Emphasis is on microflares, recent studies of different phases of flares, and propagation and trapping of flare accelerated electrons. The ongoing analysis of the observations of the previous solar cycle reaches a state where quantitative models become possible. The subject of solar flares can be broken up into several, now well defined physical problems.

1. Introduction

Flares are of great interest for the understanding of solar and stellar atmospheres. because they make fundamental processes visible. They occur in a large variety of stars, particularly

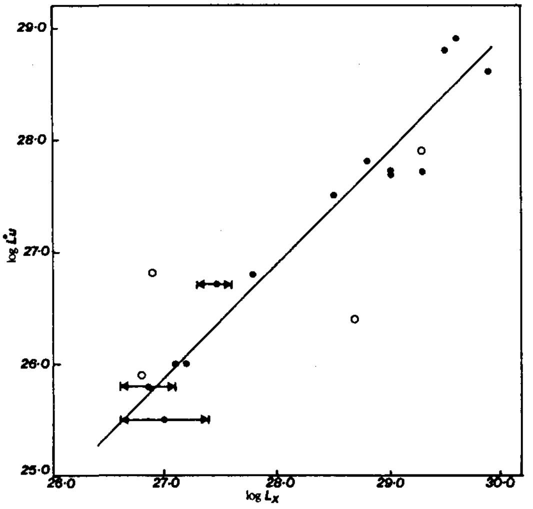

Figure 1. Time-averaged flare energy in the U band, L_u vs. quiescent soft X-ray flux, L_x (both in erg/s) of dMe stars. Open circles represent data points based on $< 15^h$ of observation and thus are probably uncertain (from Doyle and Butler, 1985).

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in their early phase and in main sequence types later than F. They clearly are related to other important processes in the atmospheres such as the heating mechanism of the corona. This has been made obvious by the correlation of the average flare power in UV and the quiescent soft X-ray fluence in dwarf M stars (Figure 1). The origin of both is generally believed to be the subphotospheric dynamo driving the coronal magnetic field.

2. Microflares

A more direct relation between flares and coronal heating is postulated in the hypothesis that a large number of very small flares provide the energy. The best evidence for such microflares occuring all the time in the solar case even in quiet regions comes from UV observations (Brueckner and Bartoe, 1983; Porter et al., 1987). Lin et al. (1984) found small amplitude band X-ray (> 22 keV) bursts during a balloon flight of a high-sensitivity detector. These events occured at a rate of about one in five minutes. Some of them, however, were shown to be associated with strong metric and decimetric type III bursts (Benz, 1983) known to be generally associated with active regions. Thus the observed HXR microflares cannot be the cause of heating in quiet regions. However, much weaker type III bursts at meter-dekameter wavelengths have been reported by Kundu et al. (1986) which occur several times per hour during quiet-Sun periods. There maybe associated HXR flares, but they are below the sensitivity of current HXR telescopes.

Small events or fluctuations have long been reported for solar radio observations. Correlation studies between Arecibo and Effelsberg (100m telescope) have shown that most radio fluctuations recorded by single dishes are instrumental (Benz and Fürst, 1987). Only in a weakly active region correlated fluctuations of typically 500Jy amplitude and 90s correlation length have been found. About 2 orders of magnitude smaller peaks were observed in quiet regions at the same wavelength of 6cm with the VLA by Fu et al. (1987). Such brightenings seem to be related to coronal X-ray bright points.

SXR microflares of dMe stars were reported by Butler et al. (1986). However, there seem to be continuous periods of several hours with no statistically significant variability (Pallavicini, 1987). The SXR emission of dMe stars is not a superposition of low level flares.

It is concluded that microflare heating of coronae may be theoretically attractive, but the observational evidence from both Sun and stars is still weak.

3. Flare Phases

Considerable effort has been made to disentangle the different phases of energy release in flares. Klein et al. (1987) have studied the onset of HXR emission in solar flares. In the pre-flash phase HXR at increasingly higher energies are observed. The onset of relativistic electrons and proton lines coincides with the flash phase. A qualitative difference seems to distinguish the two phases.

The spatial evolution of solar flares was investigated in HXR and Hα by Martin and Svestka (1988). The two emissions are not cospatial. First the HXR loop fills starting from the two footpoints. This is compatible with the idea of explosive evaporation.

Beams of down-going electrons have recently been observed in microwaves as type III bursts (Stähli and Benz, 1987). Most important is the fact that the corona is transparent to plasma emission down to densities of at least 10^{11}cm. This is where energy release in flares and other interesting phenomena occur. Since radiation in a homogeneous atmosphere could not escape from this level, emission and/or propagation must take place in a fibrous plasma. Recent works on this problem include Roelof and Pick (1989) and Poquérusse et al. (1989).

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4. Trapped Particles

Millisecond radio spikes are one of the most fascinating topics in current flare research. They are very closely related to HXR emission and typ III bursts, thus seem to have an intimate relation to the energy release. An example is shown in Figure 2.

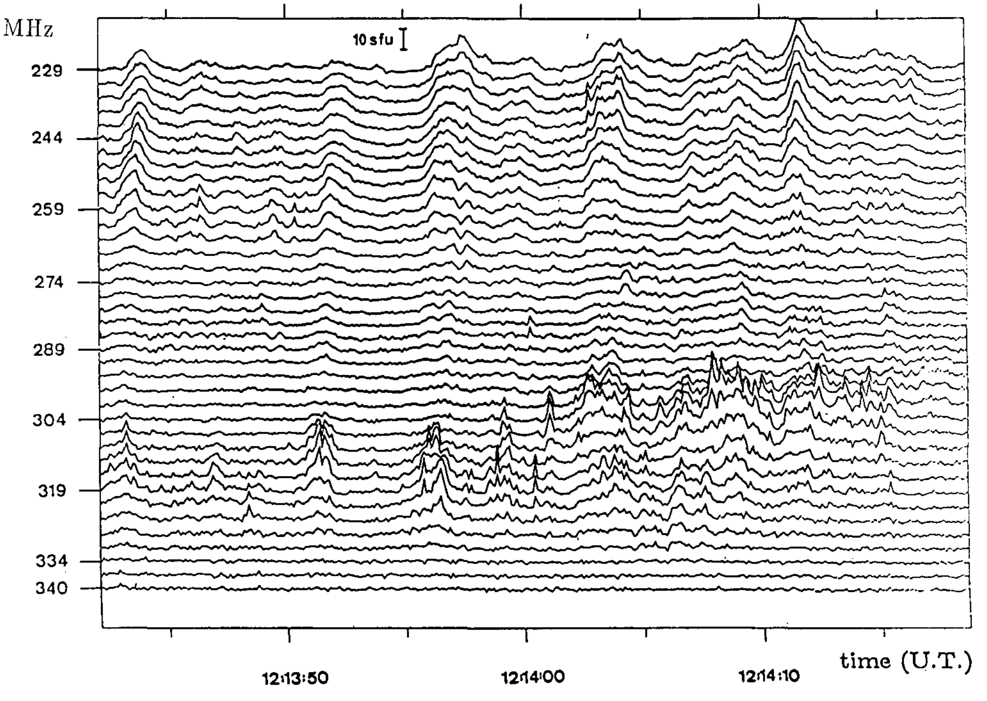

Figure 2. Radio flux in 38 channels observed by Zurich spectrometer. In the 229 – 280 MHz band (upper half) type III bursts are visible. Spikes appear loosely correlated to them in the 280 – 340 MHz band.

A possible emission mechanism is maser action of trapped electrons. Winglee et al. (1988) have numerically simulated the process and found spiky emission but with nanosecond timescale. An alternative model are thousands of electron beams injected at skew angles to the magnetic field (Li et al., 1984).

Quantitative models of synchrotron and HXR emissions of trapped and precipitating particles have been fitted to observations by several people (most recently e.g. Lu and Petrosian, 1989). A new development has started with quantitative comparison of maser emission of decimetric pulsations with HXR (Aschwanden, 1987). Combining observations at various wavelengths eliminates free parameters and reduces the range of possible models. Further progress can be expected from spatially resolved observations.

Quantitative investigations of the flare particles, plasma and magnetic field open the path for the solution of the major flare problems:

- global MHD configuration for energy release
- current sheet physics
- acceleration (or heating) of electrons

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- role of protons
- distribution of flare energy in the corona.

Flare physics is a large field and includes many interesting problems that are of general relevance. The major problems remain unsolved, but they have come into clearer focus. Considerable progress has been made in the observation of temporal and spatial evolution, as well as in the understanding of some restricted problems such as particle trapping in loops.

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