SESSION I: STELLAR FLARES

The solar–stellar connection: the relationship between flaring rates, flare power and quiescent X-ray background

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Introduction

The nature of flare activity on dMe stars (red dwarfs with strong chromospheric Hα emission lines) has been the subject of many studies. Some years ago Lacy et al. (1976) demonstrated a relationship (see also Doyle et al., 1986) between mean flare power and quiescent luminosity, in the photometric U-band. This study was extended, independently, by Skumanich (1985, 1986) and Doyle and Butler (1985) to show that the time averaged U-band power-loss due to flaring is linearly related to a star's quiescent X-ray luminosity. Skumanich also showed an inverse relationship between a star's flaring-rate and its quiescent X-ray luminosity.

These relationships have important implications, not just for dMe stars but for flaring activity and coronal heating on all stars, including, of course, our sun.

The inverse correlation of flare-rate with quiescent X-ray luminosity suggests that there may be a common magnetic driver for both. Magnetic energy may be converted via an unspecified process into macro-bursts (seen as flares) and micro-bursts (accumulated to become the X-ray luminosity). As the occurrence of macro-bursts decreases, so the occurrence of micro-bursts increases, the total outward flux of energy remaining fairly constant. So, if the background is high we may be witnessing an efficient conversion of magnetic energy to heat by way of the micro-bursts. If the release of this energy is suppressed in some way, i.e. the X-ray luminosity is low, we may expect some "build-up" resulting in larger bursts.

A "build-up" hypothesis is further supported by the inverse flare-rate versus mean flare-power relationship found for dMe stars. The suggestion is that some quantity (e.g. energy or mass) is built up at a constant rate until an instability is reached. The duration of the build-up is proportional to the amount of energy released in the subsequent flare. The quantity being accumulated is most likely energy contained in the complex magnetic field structures of active centres. This has long been considered to be the mechanism for energy storage prior to solar flares (Van Hoven et al. 1980).

Our aim in this study is to extend the dMe analysis to the sun, to explore relationships between the flaring-rate, flare power-loss and quiescent X-ray luminosity for different solar active regions. These relationships will allow us to ask questions such as: Does an active region with a bright X-ray luminosity have more powerful but infrequent flares? Does an active region with a low X-ray luminosity have many weak flares? If clear relationships can be established, for the sun and stars alike, we can surely better focus our thoughts with regard to understanding the flare process, the outstanding problem of coronal heating and the relationship between solar and stellar activities.

For this analysis we use data from the 1980 solar maximum period from the Hard X-ray Imaging Spectrometer (HXIS; on board SMM) and Hα flare data from Solar Geophysical Data (US Dept. Commerse). The method of data reduction, and details of the active region activity are given in Harrison, Pearce and Skumanich (1988).

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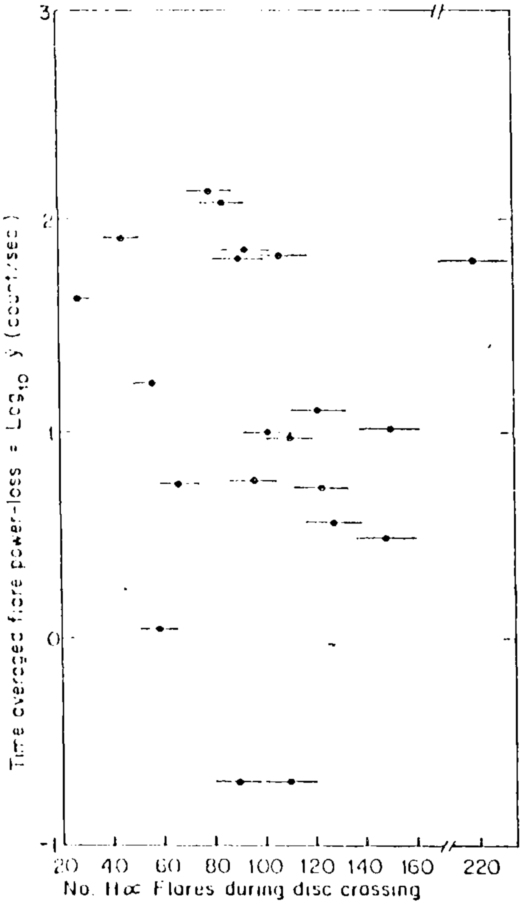
FIGURE 1: A plot of the time averaged flare power-loss, $\dot{Y}$, versus the number of Hα flares during the disc crossing, for each of the solar active regions. The vertical error bars fall within the 2% level.



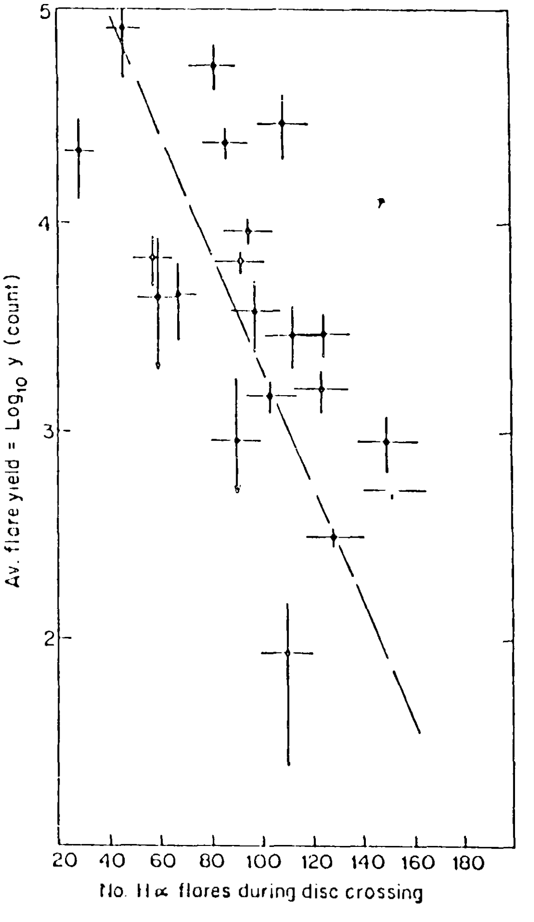


FIGURE 2: A plot of t' average flare-yield, Y, versus the number of Hα flares during the disc crossing, for each of the solar active regions. Regions not shown are 2416 and 2438, since we have no estimate for Y, and region 2779 whic i lies beyond the right hand edge of the plot. The curve, Log Y = – n/35 + 6.2 is drawn.

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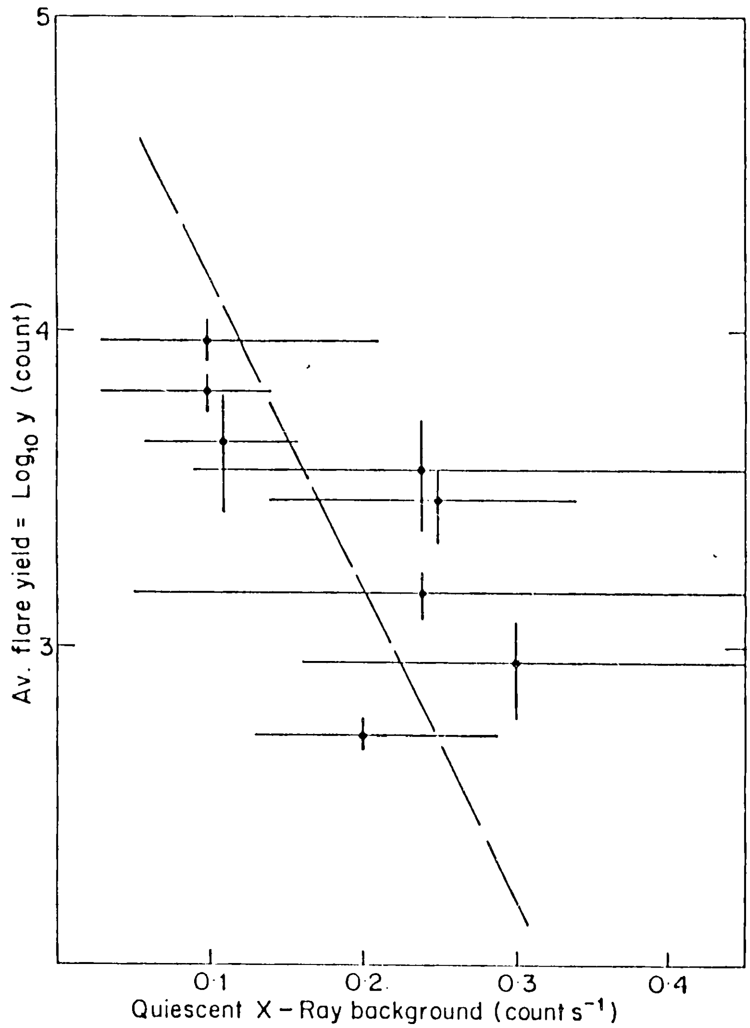
FIGURE 3: A plot of the average flare-yield, Y, versus the quiescent soft X-ray background for some of the solar active regions. The curve, $\log Y = -10 L_x + 5.2$ is drawn.



Summary and Discussion

• Overall, there is evidence for *some* correlation between the parameters investigated for the solar case, but the correlation is certainly not as pronounced as for the dMe case.

Presumably we are seeing similar processes on dMe stars and the sun, e.g. energy build-up, microbursts, flares etc..., but these processes are occurring in different environments, on stars at different stages of evolution, and this is probably reflected in the degree of correlation of the various parameters. For example, in the dMe case we may be seeing a near saturated magnetic environment, compared to the sun, where the rate of energy storage, the occurrence of breakdown etc... becomes essentially fixed because the star has a magnetically "static", near saturated environment. The individual magnetic structures may vary considerably with time but the overall picture may remain pretty constant. In a solar active region, where the overall magnetic morphology and strength may vary dramatically, since there is no near limit due to saturation, the rate of increase of energy storage or release at a particular site may be merely dependent on the magnetic activity at that site and have no relationship to such processes even within the same active region. However, the basic relationships between rate of energy storage and flare power, microburst activity and flares could still be evident, just less obvious due to the larger spectrum of activities allowed by a more

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flexible magnetic morphology, as the data shown is indicating.

• A marginally significant inverse correlation is found between flare-rate and the time-averaged flare-power loss.

• A similar, though perhaps more convincing, inverse relationship is found between the average flare-yield and the flare-rate.

Both of these relationships have considerable doubt associated with them. If we believe them, they support the dMe results where clear inverse relationships were found. The suggestion would be that a build-up process is at work in the sun and that the mechanisms of energy release dur'ng a flare are such that the rate of release of the energy is dependent on the amount of energy stored.

• For the sun, an inverse relationship is indicated between the average flare-yield and the quiescent X-ray luminosity.

In other words, brighter active regions are the sources of weaker flares. This is an important result since it indicates (a) that there is a coupling between flare activity and microburst activity and (b) a coupling between flare activity and coronal heating, in the case that the quiescent X-ray luminosity is a measure of coronal heating. The inverse relationship implies that the quiescent X-ray luminosity represents a "leaky" situation where energy cannot build up efficiently for flaring. This relationship is based on data with large associated errors. However, given the relevance of the proposed relationship to coronal heating – a major outstanding problem to the solar physicist it is important to improve Figure 3, by reducing the error bars and by including more regions. We must confirm and firmly establish the relationship before the theoretical aspects can be fully explored.

The relationship between flare-yield and quiescent luminosity was positive in the dMe case; as the background becomes stronger, so does the individual flare-yield. This is opposite to the proposed solar relationship. The positive dMe relationship was the basis of the suggestion that microbursts and flares are fundamentally the same, differing only in spatial scale, and that if the efficient release of energy by way of microbursts is subdued it is stored and released in larger bursts – the flares. Have we, then, identified a fundamental difference between solar and dMe activity? If so, this has important implications for our understanding of stellar evolution.

Acknowledgements

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