FLARE EVENT STATISTICS ON UV CETI-TYPE STARS

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Abstract. A statistical study of 228 flares on the three UV Ceti-type stars, i.e., YZ CMi, AD Leo, and EV Lac, is presented. Observations were gathered by Ichimura and Shimizu over a total monitoring time of 907 hours distributed over 18 years (1971 to 1988). Period analysis of flare activity was performed, and no periodicity was detected on the three stars for either the flare number rate or the energy rate in time-scales ranging from a year up to 14 years. Average colour of flares at peak was $(U - B) = -0.98 \pm 0.17$ and $(B - V) = 0.05 \pm 0.13$. Cumulative number distributions of flare event time-integrated energies were solved by a least-squares method on a log-log plot for a power-law function to get both the constant $\alpha$ and the gradient $\beta$, which were found to be similar among the three stars. The gradient showed that rare large flare events radiate most of the energy released by all the flare events in the monitoring time. The flare number rate and energy rate are similar if the power-law distributions are extended up to a specific maximum energy. In reality, the Kolmogorov-Smirnov test showed that the observed cumulative number distributions of flare event energy were not necessarily a power-law function. The Monte-Carlo simulation, however, indicates that the monitoring time and/or the patrol observation time interval may not be long enough to get the average flare number rate and energy rate, especially at the upper energy limits which are statistically unreliable.

1. Introduction

Stellar flares on UV Ceti-type stars have often been compared with solar flares in order to model their physical nature. Gershberg and Pikel'ner (1972) proposed that the energy of flare events is supplied by a dynamo mechanism that works in the interior of a stellar surface to produce and store energy in a magnetic field for a long time interval, and that this is followed by a local magnetic field annihilation mechanism and some accompanying processes that take place above the stellar surface, thus presenting flare events. Shakhovskaya (1989) gave various flare statistics for numerous red dwarf stars and the Sun, and strengthened the above proposal. Soft X-ray flares undoubtedly share a significant fraction of the energy released by flare activity (Byrne, 1989), and it is interesting that Rodonò and Cutispoto (1989) found infrared 'negative' flares coinciding with optical flares. It is important to study in more detail the flare activities of individual stars, because the available data can be further analysed, and possibly enhanced by using optical wavelengths.

The present study concerns three flare stars and gives a period analysis of their flare activity, their $UBV$ colours at peak brightness, and a cumulative distribution of flare event energies.

The term flare event is used to refer to all phenomena that occur in the time interval (i.e., a fraction of a minute or up to several hours) where a star increases its normal energy output until it again returns to a quiescent level (Moffett, 1974). A flare is defined as a sharp peaked increase in brightness, and most flare events in the observed sample consisted of only a single flare.

**TABLE I**
The quiescent level brightness and colours of UV Ceti-type stars studied in this paper following Andrews (1968, 1969a, b) and Blanco et al. (1968)

<table>
<thead>
<tr>
<th>Star name</th>
<th>log$<em>{10} q</em>{a}$ (erg s$^{-1}$)</th>
<th>$U - B$</th>
<th>$B - V$</th>
<th>$V$</th>
<th>$M_v$</th>
<th>Spectral type</th>
</tr>
</thead>
<tbody>
<tr>
<td>YZ CMi</td>
<td>28.60</td>
<td>0.90</td>
<td>1.58</td>
<td>11.24</td>
<td>12.3</td>
<td>M4.5Ve</td>
</tr>
<tr>
<td>AD Leo</td>
<td>29.12</td>
<td>1.06</td>
<td>1.54</td>
<td>9.43</td>
<td>11.0</td>
<td>M4.5Ve</td>
</tr>
<tr>
<td>EV Lac</td>
<td>29.11</td>
<td>1.06</td>
<td>1.58</td>
<td>10.25</td>
<td>11.5</td>
<td>M4.5Ve</td>
</tr>
</tbody>
</table>

2. Observational Data

A statistical study on the observational data of flare events is presented for three UV Ceti-type stars, i.e., YZ CMi, AD Leo, and EV Lac. The data was obtained by Ichimura (1968), Ichimura and Shimizu (1972, 1978, 1981, 1986, 1990), Ichimura et al. (1970, 1973, 1974), and Osawa et al. (1969, 1971) at Okayama Observatory. The stars’ quiescent level brightness and colours are shown in Table I.

A photoelectric patrol observation of flare stars was started in 1968 at Okayama Observatory after a request was made by the ‘Working Group of UV Ceti Type Stars’ of the IAU Commission No. 27 (Osawa et al., 1968a), and a photometer was subsequently designed (Shimizu and Norimoto, 1972) which had a three-colour filter set on a wheel that was continuously rotated at a rate of 20 Hz. The light beam was collected by a 91-cm reflector, was received from the filter set by an EMI 6256 photomultiplier, with synchronous detection then being performed. The time constant of the system was 0.2 s, and a three-channel strip chart recorder was used with a speed of 20 mm min$^{-1}$.

This simultaneous $UBV$ photoelectric observation of stellar flares had a time-resolution greater than 1 s for long monitoring times. The $U$ band was used to detect flares and measure flare events because both the quiescent level and flare radiation levels of the three stars were strong enough to measure in this band. A flare detection threshold of $\Delta U = 0.2$ mag was obtainable, however, the detection completeness limit is dependent on the quiescent level of stellar brightness, and on the observational sky conditions and zenith distance. Gershberg (1972) reported that both the completeness and the reliability of flare detection should be strictly considered so as to minimize the introduction of errors. It is suggested that some of the previous reports were too optimistic.