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A PREFLARE DIMINUTION IN THE QUIESCENT FLUX OF EQ PEGASI

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ABSTRACT

We report the occurrence of a remarkable flare event on EQ Peg as recorded by high speed photometry in the Johnson *U* band: a stellar flare event is immediately preceded by a well-defined decline in the quiescent flux of the star. The *U* band flux decays to a minimum level that is 75% of the stellar quiescent flux, and the duration of the so-called negative flare event is 2.7 minutes. We present a description of the observation and qualitatively discuss hypotheses that may eventually account for this phenomenon.

Subject heading: stars: flare

I. INTRODUCTION

EQ Pegasi (BD +19°5116; GL 896AB) is a binary system comprised of two M dwarf stars of spectral types dM3.5e and dM4.5e, following Wing and Yorka (1979) and Joy and Abt (1974). The components have apparent magnitudes $V = 10.38$ and 12.4 with EQ Peg the fainter member of the pair. The separation is 3″.7 and the parallax is 0″.155 (Gliese 1969), thus implying a physical separation of at least 24 AU. EQ Peg is characterized by strong chromospheric and transition region line emission. The transition region line surface fluxes are typically an order of magnitude greater than the corresponding line surface fluxes for the quiet Sun (Hartmann *et al.* 1979). In addition, both components of the system exhibit flare activity (Owen *et al.* 1972).

In this *Letter* we present the observation of an extraordinary flare event on EQ Peg as recorded by high speed Johnson *U* band photometry; namely, a well-defined decline in the quiescent flux of the star immediately followed by a flare. The so-called negative flares or preflare dips are decreases in the stellar flux immediately preceding a flare. These rare events have previously been observed on several flare stars, although the duration and amplitude of the negative flares have been small (Rodonò *et al.* 1979; Cristaldi, Gershberg, and Rodonò 1980; Mahmoud and Soliman 1980). As a result, the reality of the preflare dip phenomenon has been questioned. However, we report herein an observation of a negative flare with such a high amplitude and comparatively long duration that the reality of the event is undeniable.

II. OBSERVATIONS

High speed photometric observations of EQ Peg were obtained at the Cloudcroft Observatory using the 1.2 m Newtonian telescope described by Schneeberger *et al.* (1980). The data were acquired at 0.1 s integration times through a Corning 9863 glass filter (peak transmission at 3200 Å; FWHM = 1300 Å) and a copper sulfate blocking filter with an FW 130 photomultiplier tube as the detector. The combination of these optical components with an FW 130 photomultiplier tube approximates the response of a Johnson *U* band filter.

Figure 1 shows the flare event. The data have been summed over 10 points and the sky has been subtracted. The sky subtraction was performed in the following manner: we selected a portion of the sky near EQ Peg in which there were no discernable stars. We recorded the sky count rate at $t = 0$ minutes (see Fig. 1). The sky background at this time was approximately 10.6% of the star + sky quiescent level. We then recorded the sky background after the observation at $t = 30$ minutes and

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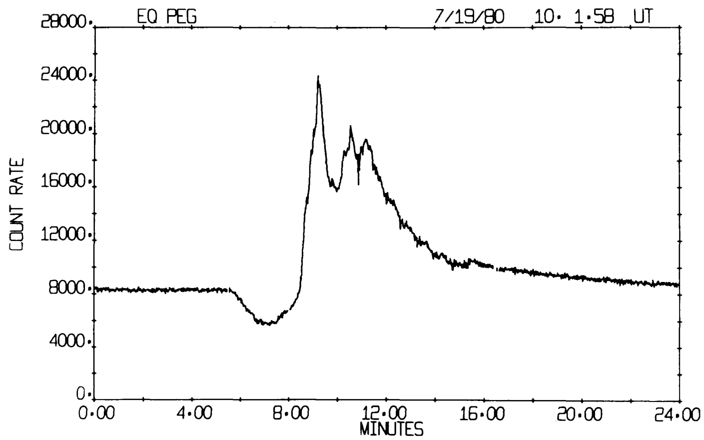

FIG. 1.—The flare event on EQ Peg showing the pronounced preflare dip. Sky was subtracted before plotting the light curve. Each plotted point is the sum of 10 of the original data points.

found the background to be essentially unchanged from the initial observation at $t = 0$ minutes. We obtained an additional observation of the sky at $t = 45$ minutes and found that the background had increased by only 2.1% with respect to the initial observation of the sky at $t = 0$ minutes. We therefore conclude that the sky background was constant during the course of observations of the negative flare event. We note, parenthetically, that a sudden onset of clouds during the event would have caused rapid fluctuations in the stellar signal and *not* the smooth decline in the stellar quiescent level shown in Figure 1.

As illustrated in Figure 1, the brightness of the star decreases at roughly 0.1 mag per minute for 2.7 minutes, then levels off at 75% of the quiescent brightness for 1 minute before the flare begins. The peak of the flare is 3 times the quiescent level brightness and is followed by two more smaller peaks separated by 60 and 30 seconds, respectively. The flare event then decays exponentially in brightness, finally obtaining the quiescent brightness 19 minutes after the start of the flare event.

III. DISCUSSION

The negative flare event we observe invites comparisons with previous observations of similar events. In particular, Rodonò *et al.* (1979) observed a preflare minimum on YZ CMi that was characterized by a low amplitude (10% of the mean preflare light level) and a short (~ 10 s) duration. The duration, at minimum light, of the event we observe is greater than the total duration of the preflare decline detected by Rodonò *et al.*, while the amplitude of the decline we report herein exceeds the amplitude of the event discussed by Rodonò *et al.* by a factor of 2.5. However, the observations presented by Rodonò *et al.* were obtained in the *B* band. The amplitude of the *U* band minimum we detect is similar to the amplitude of previous *U* band observations of negative flares (Cristaldi, Gershberg, and Rodonò 1980). In addition, Rodonò *et al.* note that the observed preflare light decrease occurred while YZ CMi was in a phase of enhanced preflare activity, and the amplitude of the minimum was not large enough to recover the quiescent stellar flux. By contrast, there are no detectable fluctuations in the quiescent flux of EQ Peg prior to the negative flare event. Thus the occurrence of a preflare minimum is not necessarily correlated with a prior enhanced level of activity at the stellar surface. Moreover, the 25% decline in the stellar quiescent flux in the *U* band implies that an area greater than 25% of the visible surface area of EQ Peg is affected. Hence the negative flare is a global event. If the presumed disturbance that stimulates the preflare minimum propagates at the local (upper photospheric) sound speed, then we find that $l = c_s t_{1/2} \approx 4.9 \times 10^7$ cm or 2×10^{-3} R_*, where we adopt $c_s \approx 6$ km s^{-1} for the local sound speed, $t_{1/2} = 80$ s and $R_* \approx 2.2 \times 10^{10}$ cm, following Allen (1976) for a star of spectral type dM4.5. While this length scale does not yield the inferred minimum affected area of the stellar surface, it does correspond to ~ 10 pressure scale heights in the stellar photosphere. Therefore a disturbance of this kind must occur simultaneously over a significant fraction of the stellar surface, as opposed to an initially local event that propagates across the stellar surface. The alternative inference is that the presumed disturbance propagates at a speed that is much greater than the local sound speed.

The physical origin of these rare events is unknown. Grinin (1976) claims that the preflare decline is due to an increase in the H^- opacity resulting from enhanced heating of the outer atmosphere of the star. The enhanced heating in this model is attributed to a flare blast wave that originates in the stellar transition region and corona and then propagates both outward from the star and through the underlying chromosphere and photosphere. The enhanced chromospheric heating is presumed to result in an increase in the H^- number density, thus temporarily increasing the H^- opacity and causing a decline in the observed stellar photospheric flux. The flare blast wave subsequently heats the upper photosphere of the star and causes a white light flare. While the hypothesis of a temporarily enhanced source of opacity is suggestive, the model proposed by Grinin (1976) is incomplete. In particular, the model advanced by Grinin (1976) does not consider the concurrent effects of (1) the decline in opacity due to the metals that constitute the principal source of electrons in the upper photosphere and temperature minimum region, (2) the decline in molecular opacities as a result of the increased heating, and (3) the enhancement of chromospheric emission lines, such as the Ca II H and K lines and the high Balmer lines, that are prominent features in the Johnson *U* band. The combination of the aforementioned factors may offset any increase in the effect of the H^- opacity as observed in the Johnson *U* band.

We now consider another hypothesis which is suggested by a form of *solar* activity that possessess phenomenological similarities to the stellar flare event we discuss herein. More specifically, *disparitions brusques* (disappearing filaments) are often followed by flarelike brightenings in the solar chromosphere (d'Azambuja and d'Azambuja 1948; Hyder 1967*a*, *b*; Pallavicini and Vaiana 1980). In brief summary, a *disparition brusque* is the result of a filament that undergoes a destabilization process. The ascending prominence[4] material is lifted out of the magnetic field region characterizing quiescent prominences and falls along field lines into the chromosphere where the kinetic energy of fall is dissipated in a flare brightening, although the flare brightening cannot be ascribed entirely to an infall-impact mechanism (Hyder 1973). Moreover, the so-called disappearance of the filament is actually the result of the velocity (wavelength) displacement of Hα emitting material during the course of narrow-band ($\lesssim 1$ Å) Hα observations. In the case of a dMe star, the destabilization and the subsequent dissipation of an off-limb filament may lead to the deposition of material into disk lines of sight, thereby providing a temporary increase in line and continuum opacities over the affected portion of the stellar disk. This event would, in turn, result in an apparent attenuation of the chromospheric line emission and Balmer continuum emission. As an illustrative example, the Ca II H and K lines and the Balmer lines beyond Hδ provide approximately 25% of the observed quiescent *U* band flux of the dM2.5e star AU Mic; in the case of UV Ceti (dM5.5e), approximately 33% of the quiescent *U* band flux is due to chromospheric line emission (Giampapa, Worden, and Hege 1982). Hence, if a sufficiently large filament on EQ Peg suffered a *disparition brusque*, then the subsequent decline in the chromospheric line emission and the Balmer continuum emission would be reflected in an easily detectable diminution of the stellar *U* band flux. Furthermore, a flarelike brightening would be expected to follow a *disparition brusque* (Hyder 1967*a*, *b*; Pallavicini and Vaiana 1980), thus explaining the observed association of a sudden decline in the *U* band light with the occurrence of a stellar flare.

The aforementioned model requires an off-limb filament seen at a preferred aspect angle, and this would account for the paucity of observations of these kinds of events. An alternative model involving *disparitions brusques* would entail a disk filament of low contrast, as seen in the *U* band, that is suddenly activated. The resulting expansion and subsequent cooling of the filamentary material would effectively increase the *U* band opacity through an increase in chromospheric line and Balmer continuum opacities. The decline in the *U* band light would then be followed by a flarelike brightening, according to the scenario of a *disparition brusque* event. In this instance, the rarity of the event would be attributable to the infrequent occurrence of *disparitions brusques* on dMe stars, in analogy to the rare occurrence of these events on the Sun.

Finally, we propose a third hypothesis that may eventually account for the preflare diminution of the quiescent light. We suggest that a disturbance composed of MHD waves increases the nonthermal broadening component of the absorption lines that characterize the severely line-blanketed *U* band region of the M dwarf stars. Thus the increased equivalent widths of the numerous absorption features would temporarily increase the mean opacity in the *U* band and, consequently, the quiescent *U* band stellar flux would decline. While detailed model calculations will eventually be required, a modest increase (a factor of ~ 2) in the Doppler widths of the absorption features in the *U* band may be sufficient to cause a detectable decline in the quiescent flux level (Kurucz 1981). We assume the disturbance that initiates the event is composed of MHD waves because the dips are always associated with flare events, and it is an empirical fact that solar flares are intimately associated with strong magnetic fields protruding through the surface of the Sun (Svestka 1976). Furthermore, we evoke MHD waves, as opposed to pure Alfvèn waves, since this kind of model would require waves with an acoustic component in order to affect the Doppler profiles of the absorption line features. However, a difficulty with this hypothesis, as well as the hypothesis proposed by Grinin (1976), is that a decline in the *U* band mean light level is only rarely observed prior to a stellar flare event. Furthermore, the radiative

[4]Following Hyder (1967*a*), we use the words *filament* and *prominence* interchangeably.

adjustment to the backwarming flux resulting from the opacity enhancement likely occurs on a time scale that is much less than the characteristic time scale for the negative flare event discussed in this investigation.

In summary, detailed model atmosphere analyses combined with high temporal and spectral resolution observations obtained over a broad spectral range will be required to ascertain the validity of these proposed explanations. These latter kinds of data will be especially difficult to acquire given the rare occurrence of negative flare events. Nevertheless, detailed observations of this unusual phenomenon may provide significant new insights on the nature and origin of stellar and solar flare activity.

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