5. FLARE SPECTRA IN DWARF STARS

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Observational evidence of transient flares which produce conspicuous changes in the total brightness and in the spectra of dwarf stars is limited, at present, to a small number of faint late-type stars. The outbursts take place with extraordinary rapidity and the duration is usually only a few minutes or hours. Accompanying spectral changes such as veiled and fuzzy absorption lines, greatly increased intensity of the bright lines of hydrogen and helium, and the appearance of an emission continuum shortward of λ 3750, have been reported.

Flares of this kind are known in three somewhat diverse groups of stars:

(1) stars involved in diffuse nebulosity;

(2) extremely low-luminosity red dwarfs;

(3) SS Cygni stars.

The sudden flares often seen in the sun are probably analogous to the examples of instability observed in stellar atmospheres. Such solar disturbances are, however, relatively minor in extent. While sufficient to excite line emission, they fail to release the large amounts of energy necessary to emit the hot continuous spectrum observed in the three groups of stars.

(1) DWARF STARS INVOLVED IN DIFFUSE DARK CLOUDS OR BRIGHT NEBULOSITY

In general, these may be classed as T Tauri stars. Flare-like effects have been found spectroscopically in about half of the stars for which slit spectrograms have been obtained. The time involved is apparently an hour or considerably more.

Two sub-groups of this class may be recognized:

(*a*) Stars of type dGe with many emission lines. These rather rare objects have been extensively observed. Without doubt the large variations of light and spectrum are due to some interaction with the surrounding nebulosity.

Strengthened hydrogen and continuous emission in the λ 3600 region,

which probably accompany the flare-like activity, are present on Mount Wilson plates of nearly all of these stars. Also, they have been reported in RW Aur [1], in DD Tau [2], in stars of NGC 2264 [3], and in other stars in Orion [4].

In the T Tauri stars the variations in total brightness are often large and comparatively slow, so that it should be possible to separate flares of short duration from the complicating large-scale variations of the star.

Further study is needed to decide upon the nature of the ultra-violet continuum. Simultaneous spectroscopic and photometric observations are required in order to correlate the intensity of the bright hydrogen lines and the ultra-violet continuum with the changes in the total light.

(*b*) Stars of type dK and dM with few emission lines. More than 700 stars belonging to this group are now known, mostly through the observations of Haro and Herbig. They are extremely faint and are concentrated in the dark and bright gas and dust clouds of the Milky Way.

From representative slit spectrograms it seems that they are much alike, having absorption spectra, on the average, of about type dK5. The H and K lines of Ca II and the Balmer lines of hydrogen appear in emission with an occasional showing of weak bright lines of He I, Fe II, and [S II].

In many of the stars the intensity of the emission lines and of total light are known to vary. Some of the slit spectrograms show enhanced continuous emission without absorption lines extending shortward of λ 3700, and Haro has observed this strengthened ultra-violet radiation on direct photographs exposed through selected filters [4]. Neither the origin of this excessive energy output or its duration are known, but it probably results from some flare phenomenon of short duration rather than a widespread thermal outburst. The ultra-violet continuum is usually accompanied by strong Balmer emission with a slow shortward decrement.

On some spectrograms of these stars, the absorption lines are distinctly shallow and fuzzy as a result of filling-in by overlying continuum, but since this veiling does not *always* accompany the ultra-violet continuum it may have a different origin.

(2) LATE-TYPE dMe STARS OF EXTREMELY LOW LUMINOSITY

Sudden outbursts in total light or spectral changes characteristic of flare activity have been recognized in about twenty dMe stars of the lowest luminosity known. The time involved in such outbursts is usually only a few minutes; in some flares marked changes in brightness have been observed

to take place within a few seconds of time. Because the occurrence of such flares is entirely unpredictable, and the exposure times for spectrograms relatively long, little is known of the spectral changes taking place during a flare.

A spectrogram of UV Ceti was fortuitously obtained on Mount Wilson in 1948 at the exact time of such an outburst[5]. While this spectrogram may represent an extreme example of a flare, the remarkable changes observed may be assumed to be characteristic of flare spectra in general. The normal dM5e spectrum was completely dominated by a spectrum showing:

(*a*) a strong continuum corresponding to a temperature higher than 10,000° K.,

(*b*) strong hydrogen emission lines 2 angstroms in width with a slow shortward decrement,

(*c*) bright lines of He I and a faint λ 4686 line of He II.

The observation of these outstanding features has not yet been duplicated in UV Ceti or found in other low-luminosity dMe stars, but lesser indications of the same effects occur on Mount Wilson spectrograms of YZ CMi, HD 196982 B, and on a McDonald spectrogram of Wolf 47 (exposed by Bidelman). Strengthened Balmer lines occur on certain Mount Wilson plates of V1216 Sgr, BD + 19° 5116 B, and DO Cep. Changes in the intensity of hydrogen emission lines have also been reported in the dMe stars 20 C 1250 (Luyten), HD 196982 (Luyten), V371 Ori (Wachmann), V645 Cen (Thackeray), and HD 234677 (Popper). Whether these variations in the spectra were accompanied by increases in the total brightnesses of the stars is not known.

(3) SS CYGNI STARS

Of this group, three stars (AE Aqr, SS Cyg, and RU Peg), at minimum light show absorption dG to dKo spectra upon which are superposed the continuous spectra of hot companions having bright lines 20 angstroms in width. The variations in radial velocity indicate binary motion with periods of less than a day.

Mount Wilson observations of AE Aqr[6] and SS Cyg at minimum light show the characteristic flare effects on some spectrograms, and Lenouvel's photo-electric observations[7] of AE Aqr reveal many flares, of a few minutes in duration, in the total light of the system.

The origin and nature of these light and spectrum changes are very

uncertain. Simultaneous observations of light and spectrum are needed to separate processes taking place in the two bodies.

Somewhat similar effects are noted in the spectral changes of the three groups of stars, but the underlying cause of the strange and unexpected behaviour, which may be quite different in the three types, invites both observation and analysis.

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