THE EMISSION LINES IN THE VICINITY OF HYDROGEN

ALPHA IN dMe FLARE STAR SPECTRA

by

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Abstract

High resolution spectral data obtained in the vicinity of hydrogen alpha have been obtained for a number of dMe stars. Centrally reversed H α emission profiles appear to be a general feature of dMe spectra. Possible mechanisms related to solar phenomena are discussed for forming this type of profile.

Dwarf M emission line stars (dMe) are main sequence stars of late K or M spectral type which have the hydrogen Balmer lines and other strong lines in emission. These stars undergo frequent flare-ups and exhibit a low amplitude light variation of constant period but changing phase. These characteristics have been attributed to the presence of solar-type magnetic surface activity such as starspots which rotate into and out of view (c.f. Bopp and Evans 1973, Torres and Mello 1973, and references therein). Mechanisms for the production of magnetic fields of tens of kilogauss to drive this activity have been proposed and discussed by Mullan (1974, 1975a) and Worden (1975). Recent analysis of observational data by Anderson et al. (1976) and Mullan and Bell (1975) have provided direct evidence for the presence of strong dMe surface fields. It is the purpose of this letter to discuss high resolution spectroscopic data obtained in the spectral regions near H α λ 6562.8.

The Data

dMe spectra covering the region of 5500 Å to 7000 Å were obtained using the Kitt Peak National Observatory Echelle Spectrograph system on the Mayall 4-meter telescope. These spectra, obtained from 17-22 Nov 1975 are of 5.1 Å/mm dispersion with a spectral resolution of .2Å, although a few spectra of 2.6 Å/mm dispersion providing a spectral resolution of .1Å. were also taken. Table 1 lists the stars and summarizes the results.

Three general features were noted on these spectra: i) The apparent double emission peaks in H α reported by Anderson and Bopp (1975) are confirmed and seem to be a general feature of dMe spectra.

ii) The sodium D lines ($\lambda 5890$, $\lambda 5896$) often appear in emission. However, the possibility that these are night sky emission lines cannot be eliminated, since the emission components are unresolved in the $.2\text{\AA}/\text{mm}$ data in which they appear. iii) The Helium I $\lambda 5875.6$ line is weakly present in emission for most of the dMe stars observed.

Intensity traces of these spectra were obtained using the Kitt Peak PDS microdensitometer system. Figure 1 shows the $H\alpha$ profiles from the $.2\text{\AA}$ resolution data for four of the stars. Figure 2 is a plot of $H\alpha$ and HeI $\lambda 5675.6$ for EV Lac with $.1\text{\AA}$ resolution. The double emission peaks in $H\alpha$ are apparent in both figures.

Discussion

As discussed by Torres and Mello (1973) and Bopp (1974), the dMe phenomena are apparently qualitatively similar to observed solar processes. The following explanations of the double $H\alpha$ emission are therefore presented in terms of solar activity.

i) The two emission peaks represent Zeeman components of $H\alpha$ split by a large magnetic field (Anderson et al. 1976).

ii) A narrow $H\alpha$ absorption line in a background photospheric spectrum is blended with a broader emission line arising in patchy emission regions on the stellar surface.

iii) The $H\alpha$ line is centrally reversed indicating an optically thick emitting region in the $H\alpha$ emission line core. Solar analogies for such a region include:

- (a) chromospheric emission regions (plages) surrounding spots,
- (b) small scale chromospheric structures such as spicules,

- (c) flares,
- (d) dense cool structures such as prominences imbedded in a hot corona.

Anderson et al. (1976) discuss the H α profile and polarization in the flare star BY Dra and present evidence that fields of 40 kilogauss are present. However, two important points are brought out. First, BY Dra is a complex system as it is a close binary with both stellar components contributing to the observed H α profile. Second, H α itself has a very complex splitting pattern. It is also to be noted that, if regions of opposite magnetic polarity lie close together on the stellar surface, as they do on the sun, Zeeman components may exhibit weak or anomalous polarization characteristics. But, as pointed out by Rust (1967), H α magnetic splitting can be modeled as a simple Zeeman triplet with the displacement of the Zeeman σ components of

$$\Delta\lambda = \pm 4.67 \times 10^{-13} \bar{g} \lambda^2 \text{ (Å)} H \text{ (Gauss) Å}$$

calculated using a mean value of the Landé g factor of $\bar{g} = 1.045$.

If the two H α emission peaks are identified as resolved Zeeman components, this indicates fields of tens of kilogauss within the H α emitting region.

The Landé g value of the strongest HeI $\lambda 5875.6$ transition is 1.167,

implying a Zeeman sensitivity comparable to H α . (i.e. $(\lambda^2 \bar{g})_{\text{H}\alpha}$

$/(\lambda^2 \bar{g})_{\text{HeI } 5875.6} = 1.12$). However, the He line profile shows no double

peak in any of our spectra. Indeed, the only non-uniformity in the He line profile is the possible presence of the nearby HeI 5876.0 transition.

The lack of He line splitting on a spectrum of .1Å resolution for EV Lac sets an upper limit of about 5 kilogauss for fields within the He line

emitting region. This result can be interpreted in several ways. It may imply that the HeI $\lambda 5875.6$ line is formed in a different emitting region with weaker magnetic fields than fields within the H α emitting volume, although physical conditions responsible for exciting HeI in dMe stars would be expected to produce H α emission from the same region as the HeI emission. We will therefore consider the possibility that the H α profile is the result of some process other than Zeeman splitting for the general class of dMe stars.

Without observations of other strong emission lines which appear in absorption in a photospheric spectrum it is impossible to rule out the possibility that the H α profile is due to the superposition of an absorption spectrum on an emission spectrum. However, it is apparent in figure 1 that the double peak profile does not differ markedly from star to star. If an underlying absorption spectrum is responsible for the H α reversal, the effect may be expected to vary depending on the strength of background spectrum and spectral type of the star. This is not the case, since the effect appears as strong in the Wolf 359 spectrum, which at spectral type M8 has a very weak background spectrum.

Central reversals in the H α ^{profile} are found in a number of solar phenomena associated with an emitting region which becomes optically thick at the center of H α . If the dMe H α profiles arise in an optically thin region, then the temperature within the emitting region can be estimated from the half width of the emission line. If the broadening is assumed to be completely Doppler, then the following relation from Aller (1963) is valid:

$$T(^{\circ}\text{K}) = 1.95 \times 10^{12} \mu \left(\frac{\Delta\lambda}{\lambda}\right)^2 ,$$

where μ is the mean molecular weight ($\mu = 1$ for hydrogen). Our H α profiles have half-widths of $\Delta\lambda \approx 1 \text{ \AA}$ implying a temperature of $4 \times 10^4 \text{ }^{\circ}\text{K}$. A region this hot would not be expected to have any H α emission. It must be concluded that unless the observed H α profile is composed of several narrow components, the emitting region must be optically thick. Solar flares often show H α reversals (Smith and Smith 1963) pointing to the possibility that the dMe H α profile arises in low-level undetected flares. However, solar flares exhibit very broad ($\sim 5 \text{ \AA}$) H α profiles presumably due to the high electron densities ($\sim 10^{13}/\text{cm}^3$) within the flaring region (Svestka 1972). Our H α profiles with widths of about $1 \text{ \AA}$ therefore imply an electron density somewhat less than the solar flare value of $\sim 10^{13}/\text{cm}^3$. In addition, the dMe H α profiles do not exhibit asymmetries often seen in solar flares. Chromospheric spicules observed at the solar limb show a centrally reversed H α profile (Zirker 1962, Beckers 1972) with the proper spectral width. However, as discussed by Bopp (1974), the large variations in emission line strength observed in dMe stars rule out emission lines originating in structures as uniformly distributed over the stellar disk as spicules. Quiescent prominences, while providing the proper patchy distribution, only seldom have centrally reversed H α profiles (Engvold and Livingston 1971) and their H α widths are generally much less ($\sim .5 \text{ \AA}$) than the dMe widths. Patchy chromospheric emission regions (plages) may work, although in the sun H α is not seen in emission in these regions. We must conclude that while the dMe H α profile indicates an optically thick emitting region with an electron density less than $10^{13}/\text{cm}^3$, no single

solar phenomenon fully matches the observations.

The presence of Helium emission lines in quiescent dMe spectra (Wilson 1961) provide the possibility to study another aspect of dMe stars. A 3000 °K photosphere cannot excite these lines. However, UV radiation from a hot corona causing photoionization followed by recombination will provide Hydrogen and Helium emission in such solar features as prominences (Tandberg-Hanssen 1974). Hot dMe coronas have been discussed by Kahn (1969) and Mullan (1975b). Additional high-resolution observations of Hydrogen Balmer lines and both singlet and triplet Helium lines may thus provide information not only on the emitting region itself but on the general structure of the outer stellar atmosphere as well.

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TABLE 1

Star	Spectral type	H α emission	HeI λ 5875.6 emission	Na D emission	Reference
GT Peg	dM 3.5e	double	single	single	1
EV Lac	dM5e	double	single	single	1,2
Ross 248	dM6e	double(?)	-	absorption	1
FF And	dM0e	double	single	?	1
^a YY Gem	dM0.5e	single	?	?	1
Ross 614	dM5e	double	single	single	-
Wolf 359	dM8e	double	single	single	2
^b EQ Vir	dK5e	double	?	?	1
SZ UMa	dM1	absorption	-	absorption	2

1. Torres and Mello (1973)

2. Veeder (1974)

^aYY Gem is a close binary with a ^d.8 period. Both components show single H α emission. However, the rotation may be large enough to smear any double emission which is present.

^bDouble emission peaks reported by Anderson and Bopp (1975).

FIGURE CAPTIONS

Figure 1: Traces of H α emission in four dMe stars. Spectral resolution of $.2\overset{\circ}{\text{\AA}}$.

Figure 2: Traces of H α and HeI $\lambda 5875.6$ emission lines in the dMe star EV Lac. Spectral resolution of $.1\overset{\circ}{\text{\AA}}$.