THE BALMER DECREMENT IN RED DWARFS SPECTRA DURING THE FLARES AND QUIESCENT STATE

M.M.KATSOVA, Sternberg State Astronomical Institute,
Moscow State University, 119899 Moscow V-234, U.S.S.R.

ABSTRACT. The Balmer decrements observed from flare stars during the flares and out-of-flare are analyzed on the basis of our new consideration of hydrogen atom kinetics. The steep Balmer decrements correspond to the emission source with electron density $n_e \leqslant 10^{13}$ cm^{-3} optical depth at the Lα line centre $\tau(L\alpha) \leqslant 10^7$ for T=10^4. The low-sloping Balmer decrement, being typical for flare maximum of red dwarfs as well as for several flare stars with measurable X-ray emission out-of-flare, are described by $n_e = 3 \cdot 10^{13} - 10^{14}$ cm^{-3} and $\tau(L\alpha) = 10^7 - 10^8$ for T=$(1-1,5) \cdot 10^4$ K.

1.INTRODUCTION. THE THEORETICAL BALMER DECREMENT.

The problem of interpretation of the Balmer decrements of red dwarfs out-of-flare and especially during the flares is far from being solved. Recent observations with high spectral and temporal resolution are called for new consideration of this problem. First of all, the hydrogen atom kinetics under conditions of late-type star chromosphere is studied. The solution of statistical equilibrium equations is carried out with approximate consideration of radiative transfer problem for motionless medium (Bruevich, Livshits, this proceeding).

Let us define the Balmer decrement (B.d.)as the ratio of the flux in a given line to the Hγ line flux:

$$\frac{F(Hn)}{F(H\gamma)} = \frac{n_i}{n_5} \cdot \frac{A_{i2}}{A_{52}} \cdot \frac{h\nu_{i2}}{h\nu_{52}} \cdot \frac{\beta_{i2}}{\beta_{52}}$$

where n_k - the k-level population, A_{k2} - the probability of spontaneous transitions and β_{k2} - the averaged over the layer escape probability of a photon. Taking the escape probabilities β and level populations from the theoretical calculations, we found the theoretical B.d. When $\tau<10$ at the line centre considered, so approximate expression for β is not valid. In such a case, the profiles of the higher Balmer line were calculated.

The theoretical B.d., for instance, for T=10^4 K and electron densities $n_e=10^{13}$ and 10^{14} cm^{-3} are given at Fig.1. By each of curves theoretical depth at the Lα line centre $\tau(L\alpha)$ is written. Firstly, it

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is easy to see that the relative Hα- and Hβ-fluxes are most sensitive to the $\tau(L\alpha)$ variations. The same conclusion was made earlier by Grinin, 1969. Secondly, there is a certain value of $\tau(L\alpha)$ for each fixed value of T and ne in a layer, exceeding of which leads to a change of the B.d.slope: instead of being steep, decrement becomes low-sloping one. This transition occurs when $\tau=10$ at the Hδ line centre; that corresponds to $\tau(L\alpha)=3\cdot10^7$ for $n_e=10^{14}$ cm^{-3} and $T=10^4$ K. Otherwise, when the Balmer lines considered become optically thick, the slope decreases noticeably and it can become inverse for some range of $\tau(L\alpha)$: for instance, the Hδ-line fluxe can be larger than the Hγ-line flux. It should be noted that the curve for $\tau(L\alpha)<10^6$ on Fig.1 does not vary practically for $n_e<10^{13}$ cm^{-3} and does not depend on concrete value of $\tau(L\alpha)$. For $T>10^4$ K and the same densities $n_e=10^{13}$-10^{14} cm^{-3}, B.d. can be more sloping one at lower $\tau(L\alpha)$ by several orders of magnitude.

2. INTERPRETATION OF THE BALMER DECREMENT OBSERVED.

a)UV Ceti-stars out-of-flares Full set of the observational B.d. of quiescent flare stars was published by Gershberg, 1974a and Pettersen, Hawley, 1988.

Comparison of these data with the above mentioned B.d. theory (Fig.2, 3) shown that the observations are described quite well by the theoretical curve with $T=10^4$ K, $n_e=10^{13}$ cm^{-3} and $\tau(L\alpha)=10^8$.
1988 data allow to separate two types of behaviour of B.d., which conform to two sets of parameters at $T=10^4$ K: 1) $n_e=10^{13}$ cm^{-3}, $\tau(L\alpha)\leqslant10^8$; and 2) $n_e\leqslant10^{13}$ cm^{-3}, $\tau(L\alpha)<10^6$. This distinction is due to, more probably, decrease of electron density in chromospheres of these stars. An analysis shows that these two types of stars are distinguished by the X-ray levels: for stars with more low-sloping Balmer decrements Lx is higher by 1-2 orders of magnitude.

b)stellar flares Analysis of flare spectra, obtained with temporal resolution of a few minutes and discussed by Gershberg, 1974b, shows that in the first approximation they are described by theoretical B.d. with $T=10^4$ K, $n_e=10^{14}$ cm^{-3} and $\tau(L\alpha)>3\cdot10^7$ (Fig.4). For several spectra near the flare maximum, characteristic are somehow higher temperature and/or larger optical depth at the Lα line centre. Even for the flare 11 Dec.1965 on EV Lac we were able to trace the evolution of B.d.: its slope becomes steeper as the flare decays during 15 minutes (observations were made with 3-min temporal resolution).

Modern observations allow to give a more detailed analysis of B.d. evolution. Fig.5 shows comparison of the observations of 4 March 1985 flare on YZ CMi (Doyle et.al,1987) with the results of theoretical calculations. It is seen, that B.d. is much more low-sloping at the emission lines maximum than out-of-flare. This B.d. is consistent with the temperature $T=10^4$ K, electron density $n_e=10^{14}$ cm^{-3} and $\tau(L\alpha)=3\ 10^7$. Observations at the maxima of several other flares show that B.d. can be low-sloping and even inverse, that corresponds to some higher temperatures ($T\leqslant2\cdot10^4$ K). Subsequently, decrease of plasma opacity at all the lines and/or some decrease of electron

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density occur.

Parameters of low-temperature, dense emission source, forming after the U-band flare maximum, are good agree with our gas-dynamic model of stellar flare (Katsova and Livshits,1988).

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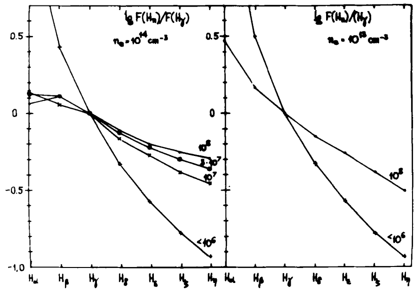

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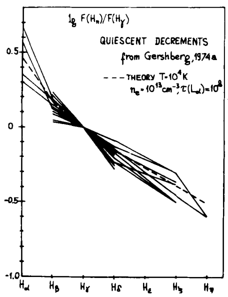

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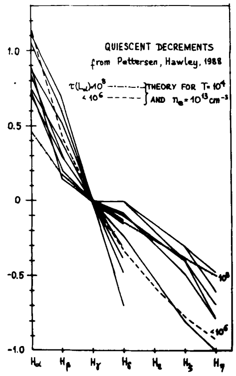

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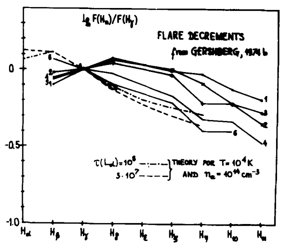

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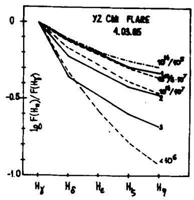

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