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Emission Lines of Dwarf Novae Accretion Disks

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Abstract. We derive the temperature and density structure of the accretion disk of the dwarf nova U Gem in quiescence from 3D radiative line and continuum transport calculations of a differentially rotating disk.

1. Introduction

It is not yet understood how high temperature emission lines like He I and low temperature emission lines like Ca II occur with similar profile shapes in accretion disks of quiescent dwarf novae. In this study, we fit the orbital mean of the optical spectrum of U Gem by varying the density and temperature distribution of the disk in terms of radial power-laws.

2. Observations

Time resolved spectra of double peaked emission lines from the quiescent accretion disk of U Gem were taken during 6 nights in Feb 1990 with the Intermediate Dispersion Spectrograph at the Isaac Newton Telescope on La Palma. The IPCS detector was used to cover wavelength ranges $\lambda3770 - \lambda4282$Å and $\lambda4250 - \lambda4750$Å and a CCD detector was used to cover $\lambda6520 - \lambda6720$Å. The instrumental resolution of 30 km s^{-1} is much smaller than the Doppler broadening due to the orbital motion in the accretion disk. Two nights were devoted to each wavelength region, and on each night the observations covered roughly a full binary orbit of the system. The He I emission lines did not exhibit an s-curve. The spectra were averaged to obtain the mean spectrum under analysis (Fig. 1).

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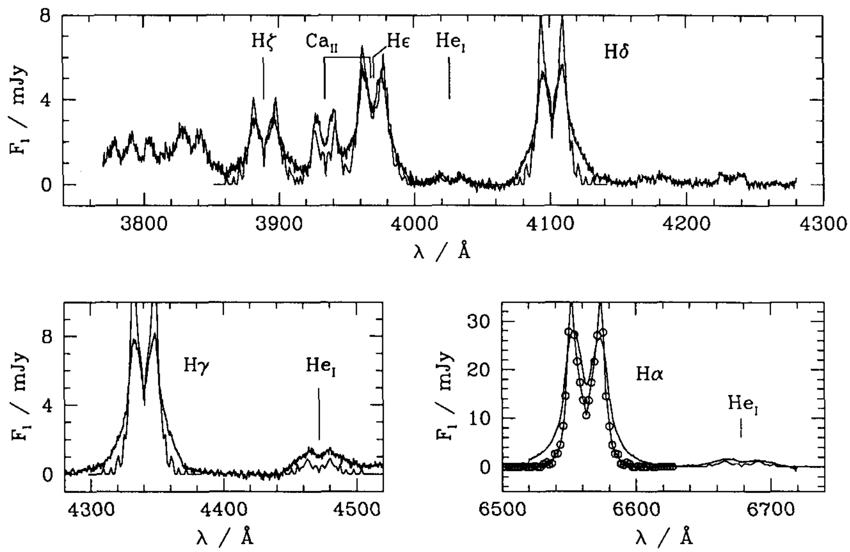

Figure 1. Continuum-subtracted and orbital averaged optical spectrum of U Gem during quiescence and model fit of the most prominent emission lines.

3. Model assumptions

We assume a Keplerian disk ($V_{\rm rot} \sim R^{-\frac{1}{2}}$). For a given electron temperature

$$T_{\rm e}(R) = T_0 R^{-k}, \tag{1}$$

intrinsic isotropic velocity disturbance V_Δ, and an initial baryonic density distribution

$$N(R,Z) = N_0 R^{-m} \exp\left(\frac{-Z^2}{2H^2(R,T,V_\Delta)}\right) \tag{2}$$

we solved the equation of hydrostatic equilibrium together with the ionisation balance. The resulting hydrostatic structure was used as input to a modified version of the three dimensional spatially implicit radiative transfer method (Adam 1991; Hummel 1994) in order to calculate the line and the continuum radiation of the accretion disk under the additional assumption that LTE governs the occupation numbers. Calculations were done on a grid consisting of $60 \times 60 \times 60$ spatial gridpoints which enclose a region of $2R_{\rm d} \times 2R_{\rm d} \times 4H(R_{\rm d})$ with a spectral resolution of $\Delta\lambda = 2$ Å.

Since we only account for light from the accretion disk itself, continuum-subtracted spectra were used for comparison between observation and theory.

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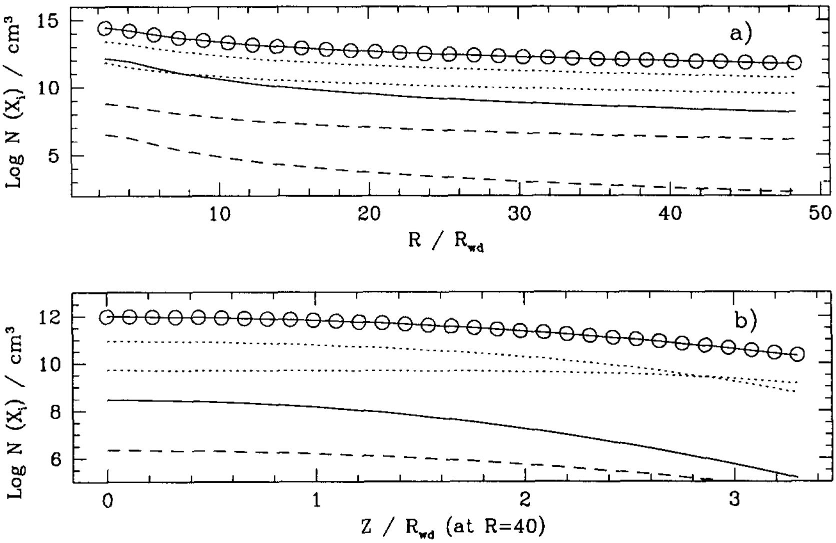

Figure 2. Radial (a) and vertical (b) distribution of the most abundant ionisation stages. From top to bottom: H II (—), electron density N_e (o), He I (···), He II (···), H I (—), Ca III (– – –) and Ca II (– – –)

4. Multi Parameter Fits

Fundamental stellar parameters for U Gem were taken from the literature, as $M_{wd} = 0.57M_\odot$ (Friend et al. 1994), $i = 70^0$ (Zhang & Robinson 1987), $R_{wd} = 5 \times 10^8$ cm (Panek & Holm 1984), while $R_d = 50R_{wd}$ is derived from the peak separation.

Up to 5 parameters were varied using the downhill simplex method (Press et al. 1992). These were N_0 and m for the density, T_0 and k for the electron temperature and V_Δ. The nominal distance of $D = 80$ pc (Marsh et al. 1990) was varied by up to 15% for a fine scaling of the intensity. The fitting procedure was performed several times with different initial parameters in order to confirm or reject the global character of the minimum in χ^2.

5. Results

The best fit spectrum (Fig. 1) is found for a rather isothermal accretion disk with $T_0 = 14\,160$ K, $k = 0.070$, a steep density gradient of $m = 2.36$, and for which $V_\Delta = 1$ Mach has been kept constant. The disk surface density $\Sigma(R)$ decreases with R (Fig. 3). The minimum of $\chi^2 = 5.18$ is found at a distance of $D = 68$ pc.

The quiescent disk is optically thin in the continuum at $\lambda = 5\,000$ Å for a pole-on view (Fig. 3). The model disk is completely ionized (Fig. 2) and because

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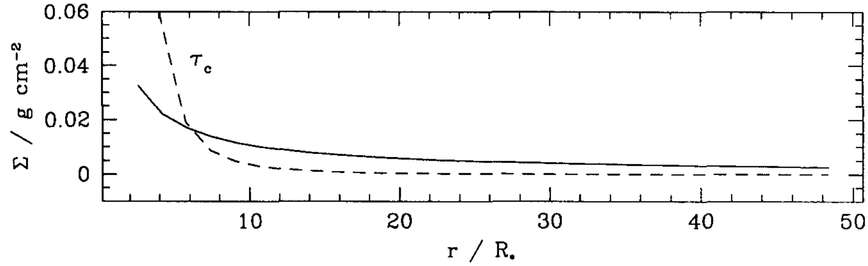

Figure 3. Radial run of the surface density $\Sigma(R)$ (—) and the continuum optical depth $\tau_c(R)$ at $\lambda = 5\,000$ Å (- - -)

of the flat temperature distribution, the density distribution in the disk controls the ionisation fraction distribution of Ca and He.

The remaining broad emission wings in Hα, Hβ, and Hγ are presumably due to Stark broadening.

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Discussion

J. Smak: The helium lines come predominantly from the hot spot area (the S-wave).

K. Horne: In this U.Gem data set, the S-wave from the gas stream is absent, so the HeI emission is from the disk.

J. Smak: The temperature cannot be that high since *(a)* for dwarf novae at quiescence we have observational estimates of $T \sim 4000 - 6000$ K. *(b)* at temperatures $T > 10000$ K the thermal instability would develop (leading to an outburst).

W. Hummel: Remember that this gas is optically thin, so that $T_{eff} \simeq T_{gas} \times \tau$, and so even with $T_{gas} \sim 13000$ K, we have $T_{eff} < 7000$ K, consistent with the disk being in the quiescent state.

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