## Determination of the Parameters of ULXs with Model Grids of Extended Atmospheres

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Abstract. In current work we continued study of wind parameters of ultraluminous X-ray sources (ULXs) using model grids of extended atmospheres. We present sets of models with temperatures from 18000 up to 56000 K as a line equivalent widths (EWs) and their ratios diagrams. The fundamental wind parameters for some spectrally studied ULXs were estimated using EW diagrams. Also, influence of the wind velocity law on the equivalent widths of observed emission lines was investigated.

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Strong radiative-driven winds are characteristic not only of most classes of massive stars, but also of binary systems with supercritical accretion, such as ultraluminous X-ray sources (ULXs). Fabrika et al. (2015) have shown that optical spectra of ULXs are similar to those of LBV and WNLh stars (late nitrogensequence WR stars with hydrogen lines). The wind parameters estimates can be obtained using line EWs diagrams of the corresponding grids of models. In this work we continued study of ULXs winds using EWs diagrams of hydrogen and helium lines started in Kostenkov et al. (2020).

Model were calculated with CMFGEN code (Hillier & Miller 1998) with temperatures 4.25  $\leq \log T_* \leq 4.75$  (step 0.025), mass-loss rates  $(M_{\odot} \mathrm{yr}^{-1})$  $-6.5 \leq \log \dot{M} \leq -4.5$  (step 0.1) and wind velocity law  $\beta = 1.0, 1.5$  with terminal velocity  $V_{\infty} = 800 \,\mathrm{km \ s^{-1}}$ . Other parameters are similar to those used in Kostenkov et al. (2020). EWs diagrams for  $\beta = 1.5$  are presented in Fig. 1. Higher  $\beta$  significantly enhance emission peaks, but also reduce lines widths. Difference in  $\beta$  between our model grids mostly affect mass-loss rate estimates by  $\log \dot{M} \approx 0.1$ . We determined wind parameters of NGC 5408 X-1 using presented above EWs diagrams. Best-fit of observed spectra was obtained with temperature  $T_* = 35480 \,\mathrm{K} \ (\log T_* = 4.55)$ , mass-loss rate  $\dot{M} = 2 \times 10^{-5} \,M_{\odot} \mathrm{yr}^{-1}$  and velocity law  $\beta = 1.5$ . Spectrum of NGC 5408 X-1 with model is shown in Fig. 2.

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Fig. 1. Equivalent widths diagrams of model grid with  $\beta = 1.5$  for ULXs for spectral resolution 5Å; left: H $\alpha$  (grey lines) and He II  $\lambda$ 4686 (black lines); right: He I  $\lambda$ 5876 (grey lines) and He II  $\lambda$ 4686 (black lines).



Fig. 2. The observed spectrum of ULX in NGC 5408. (grey solid line; VLT/FORS2 archive data, the observation date is 2020 April 12) compared with the model spectrum smoothed with a spectral resolution of 5Å (black solid line). He I lines are marked with black solid lines.

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