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Chemical Abundances of the Secondary Star in the Black Hole Binary A0620-00

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Abstract

Using a high resolution spectrum of the secondary star in the Low Mass X-ray Binary (LMXB) A0620-00 we have derived the stellar parameters and the veiling caused by the accretion disk in a consistent way. We have used a χ^2 minimization procedure to explore a grid of 600000 synthetic spectra computed for a plausible range of both stellar and veiling parameters. Assuming the best model parameters, we have studied elemental abundances of Fe, Ca, Ti, Ni, Al, and obtained abundance values close or slightly higher than solar. We have also analyzed the Li abundance which is unusually high for a star of this spectral type and relatively low mass.

1.1 Introduction

We have analyzed the spectrum of the secondary star in the LMXB system A0620-00. The compact object has a dynamical mass estimated at 11.0 ± 1.9 $M_\odot$ (Gelino *et al.* , 2001). The companion is a K type star (McClintock & Remillard, 1986) veiled by the emission produced by the accretion disk. The spectral lines of the tidally locked secondary star are broadened due to its fast rotation. The abundances of chemical elements in the atmosphere of the secondary star may provide information on possible nucleosynthesis processes in the progenitor of the compact object (as discussed in Israelian *et al.* , 1999).

1.2 Observations

1.2.1 Stellar Spectrum

The secondary star (V$\sim$18.3) was observed with UVES at VLT using a configuration that provided a dispersion 0.029 Å/pixel in the blue arm (4800 - 5800 Å) and 0.035 Å/pixel in the red (5800 - 6800 Å). Short exposures (480 - 540 s) were used in order to properly sample the orbital phase. This intended to avoid as much as possible the smearing of spectral lines associated to the radial velocity change during the orbital motion.

Radial velocities from each individual spectrum were derived using the ephemeris by Casares *et al.* (2004, in preparation). We shifted and combined the individual spectra. After binning by a factor 9 the final spectrum had a signal-noise ratio of 85 in the continuum. This spectrum is displayed in *Fig. 1.1*.

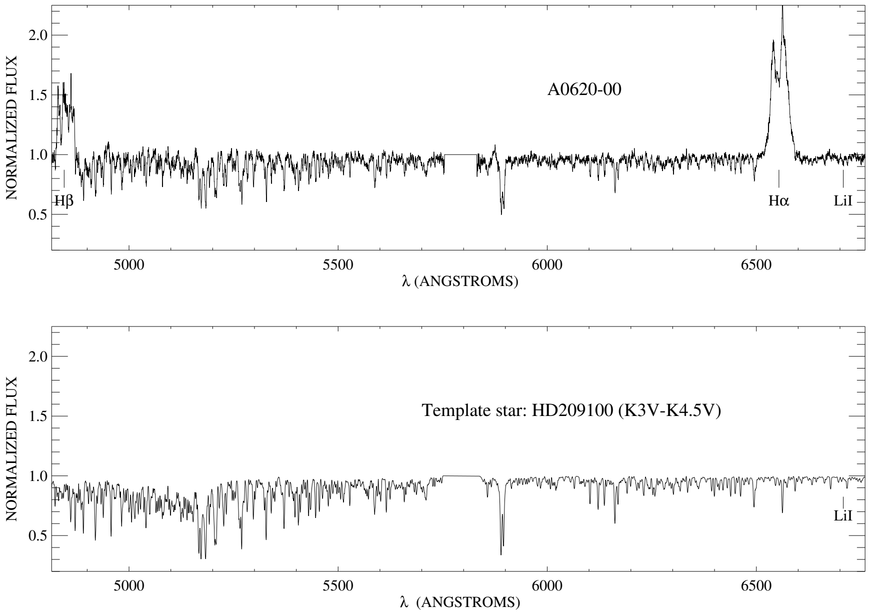

Fig. 1.1. Observed spectrum of the secondary star of A0620-00 and spectrum of a properly broadened template HD209100 (spectral type K3V-K4.5V)

1.2.2 Telluric and ISM Spectrum

In our final spectrum there are several features which can be affected by telluric lines and interstellar medium (ISM) absorptions. In order to be sure that our spectral analysis would not be affected by this two types of contamination, we obtained from our own observations a telluric and ISM spectrum and properly corrected for them. The large difference in broadening between stellar lines (∼95 km/s) and telluric lines (∼9 km/s, the instrumental resolution), allow to fit a cubic spline to the stellar features in the binned spectrum of the star. This fit was subtracted to each individual unbinned spectrum properly taking into account for the radial velocity of the star. The combination of the the residual spectra gave a noisy telluric and ISM spectrum where we tentatively identified several of the diffuse interstellar bands listed in Herbig (1995). We verified that these bands did not affect the stellar lines chosen in our abundance analysis.

1.3 Stellar Parameters

We used Kurucz models of atmospheres, the spectral synthesis code MOOG (Sneden *et al.* , 1973) and a line list which provides an excellent fit to the solar high resolution spectrum of Kurucz *et al.* (1994). First, we tried to infer the parameters of the secondary star in A0620-00 from the spectrum itself. We selected several spectral features containing in total 24 absorption lines of FeI with excitation potentials between 0.5 and 4.5eV. We produced a grid of synthetic spectra for these features considering five free parameters. Three to characterize the star atmospheric model: its effective temperature, T_{EFF}, its superficial gravity, $\log g$ and its metallicity, [Fe/H]; and other two to take into account the effect of the

Table 1.1. *Ranges and steps of model parameters.*

PARAMETER	RANGE	STEP
T_{EFF}	4000. $\rightarrow$ 5300. K	100. K
$\log g$	3.5 $\rightarrow$ 5.	0.1
[Fe/H]	$-0.8 \rightarrow 1.$	0.05
f_{4500}	0. $\rightarrow$ 0.4	0.05
m_0	0. $\rightarrow$ -0.00016	-1.778E-05

accretion disk emission in the stellar spectrum. This effect, named veiling, is characterized by the ratio between the flux of the accretion disk and the flux of the stellar continuum. It was assumed to be a linear function of wavelength and thus characterized by two parameters f_{4500}, veiling at 4500 Å and m_0, the slope. These five parameters were changed according to the steps and ranges given in *Table 1.1.* Notice that the steps for the veiling slope were chosen to cover all the possible combinations of veiling at different wavelengths taking into account the step on f_{4500}.

The observed spectrum was compared with each of the 600000 synthetic spectra in the grid via a χ^2 minimization procedure that provided the best model fit. Using a *Boostrap Monte-Carlo method* we defined the confidence regions (at 1σ) of the five free parameters and determine as most likely values: $T_{EFF} = 4900 \pm 150$ K, $\log g = 4.2 \pm 0.3$,[Fe/H]$= 0.25 \pm 0.1$, $f_{4500} = 0.30 \pm 0.05$ and $m_0 = -0.00014 \pm 0.00002$.

Confidence regions were determined using 1000 realizations. The corresponding histograms are displayed in *Fig. 1.2*. Our measurements are consistent with the previous determination of veiling for this system (Marsh *et al.* , 1994). These authors find a veiling of 17 $\pm$ 3 per cent at Hα and 6 $\pm$ 3 per cent at Hβ, while we obtain 20 $\pm$ 5 per cent and 0 $\pm$ 5 per cent, respectively.

1.4 Stellar Abundances

Using the derived stellar parameters we analyzed various spectral regions. The rotational broadening of 95 km/s and a limb-darkening $\epsilon = 0.65$ was assumed based on Casares *et al.* (2004, in preparation). As an example, we have displayed in *Fig. 1.3* one of the spectral regions. We also analyzed the spectrum of a template late type star, HD 209100, which was broadened using the rotational profile inferred from the observed spectrum of A0620-00. The abundances obtained for the comparison star are close to solar except the Li abundance which is much lower. All the abundances in *Table 1.2* are referred to the solar values which we adopted from Anders & Grevesse (1989). The abundance analysis have been done assuming local thermodynamic equilibrium (LTE).

The final abundances for Fe, Ca, Ti, Ni, Al and Li are given in *Table 1.2*. The Fe abundance listed in the table is the result of a reanalysis of individual Fe features taking into consideration the weak lines affecting each blend. For the rest of the elements we have analyzed only those spectral features where the contribution from the element was dominant or very significant. The errors were estimated considering the uncertainty on the location of the continuum, the signal-noise ratio and the errors associated of the determination of the stellar parameters and veiling. The most important source of error is the uncertainty on the

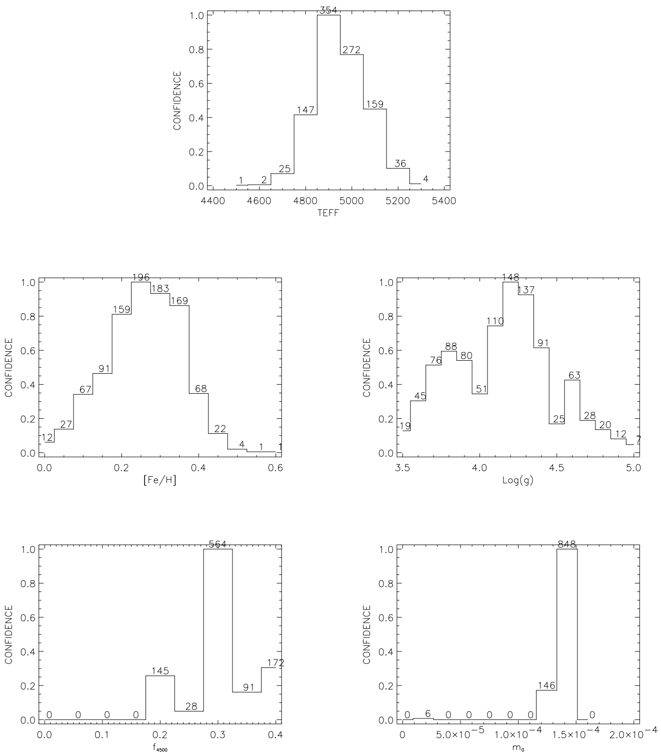

Fig. 1.2. Distributions obtained for each parameter using Montecarlo simulations. The labels on the top of each bin indicate the number of simulations consistent with the bin value. The total number of simulations was 1000.

Table 1.2. *Final abundances. The errors are estimated from the dispersion of the measurements from different features.*

ELEMENT	$[M/H]_{LTE}$
Fe	0.15 ± 0.20
Ca	0.10 ± 0.10
Ti	0.35 ± 0.40
Ni	0.25 ± 0.20
Al	0.40 ± 0.20
ELEMENT	$\log N(Li)_{LTE}$
^{7}Li	2.20 ± 0.20

continuum location due to the rotational broadening and to the signal-noise of the observed spectrum.

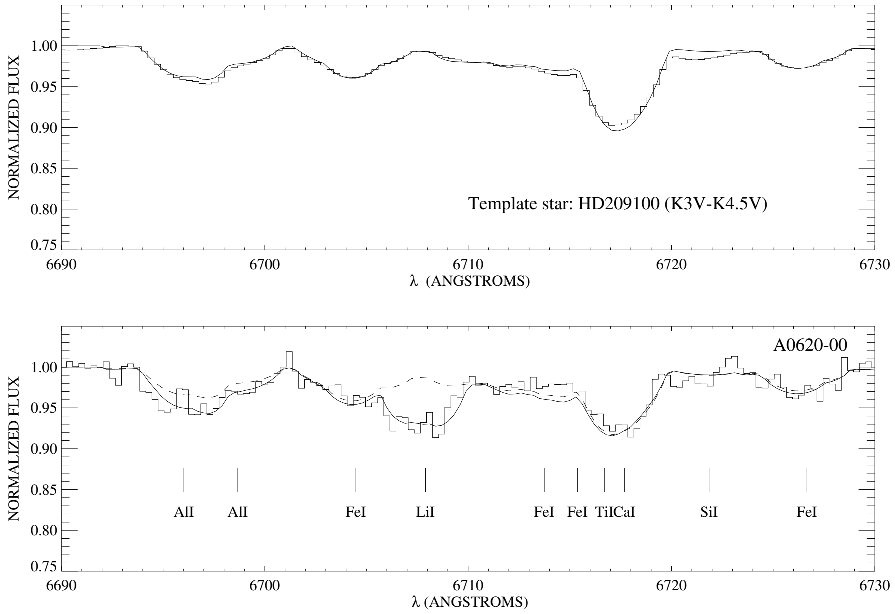

Fig. 1.3. Best synthetic spectral fits to the UVES spectrum of the secondary star in the A0620-00 system (bottom panels) and the same for a template star (properly broadened) shown for comparison (top panels). Synthetic spectra are computed for solar abundances (dashed line) and best fit abundance (solid line).

1.5 Conclusions

We have obtained a high quality spectrum of the secondary star in A0620-00. We have set up a technique that provides a determination of the stellar parameters of this star and takes into account any possible veiling from the accretion disk. We find $T_{EFF} = 4900 \pm 150$ K, $\log g = 4.2 \pm 0.3$ and a veiling of less than 15 per cent in the red part of the optical spectrum. We determine the abundances of Fe, Ca, Ti, Ni, Al and Li. The first five elements give abundances close or slightly higher than solar. These results cannot confirm a possible explosive event at the formation of the compact object, neither exclude it. The Li abundance is high for this kind of star as it was previously noticed by Martín *et al.* (1994), indicating either that this is a young system, or the existence of a Li production-preservation mechanism.

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