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THE TRAPEZIUM STARS. PRELIMINARY RESULTS ON DETAILED ATMOSPHERE MODELING

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RESUMEN

Se presenta un estudio espectroscópico de las estrellas en el cúmulo del Trapecio de la nebulosa de Orión. Determinamos los parámetros estelares de las estrellas tipo B0.5V, θ^1 Ori A y D. Se estudian las características espectrales variables de θ^1 Ori C y se consideran algunas consecuencias en el modelado de la atmósfera estelar.

ABSTRACT

A spectroscopic study of the Trapezium Cluster stars in the Orion Nebula is presented. We determine the stellar parameters of the two B0.5V stars θ^1 Ori A and D. The variable spectral features of θ^1 Ori C are studied, and some consequences on the modeling of the stellar atmosphere are considered.

Key Words: **H II REGIONS — ISM : JETS AND OUTFLOWS — STARS : MASS LOSS — STARS : PRE-MAIN SEQUENCE**

1. INTRODUCTION

Inside the Orion Nebula is the Trapezium Cluster (θ^1Ori), a massive star cluster responsible for the ionisation of the nebula. These are young, massive stars recently born from the ISM, and therefore should share the same chemical composition. Within a project aimed at studying the interaction between massive stars and the ISM surrounding them and from which they were born, we have selected as first target the Orion Nebula. We want to compare results obtained with usual tecniques in stars and H II regions, looking for consistency between chemical composition and stellar parameters (effective temperature, luminosity, ionising flux distribution).
We present preliminary results on detailed atmosphere modeling of the Trapezium Cluster stars.

2. OBSERVATIONS AND METHODOLOGY

For this study we use INT+IDS235 spectra of the four Trapezium Cluster stars in the range 4250 − 4750 Å obtained on 10/01/99, and between 4000 and 5000 Å observed on 21/12/02. The S/N is about 200 and the resolution is 7500. The star θ^1 Ori C is known to have variable spectral features, so we also use some of the spectra obtained by Reiners et al. (2000), kindly provided by O. Stahl. These are high resolution and high S/N FEROS spectra.
After reducing, rectifying and correcting the spectra from radial velocity, we use the metal lines for determining the projected rotational velocity.

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For the stellar parameters determination, we have used FASTWIND (Santolaya–Rey et al. 1997), a non-LTE, unified model atmosphere code, treating photosphere and wind simultaneously, and recently updated including an approximated treatment of metal line blocking and blanketing effects (see Herrero et al. 2002).

3. SPECTROSCOPIC STUDY

3.1. θ^1 *Ori A and* θ^1 *Ori D (HD37020/23)*

HD37020 is a eclipsing binary system with a period of 65.4 days and a magnitude outside eclipse V = 6.75 (Lohsen 1976). The spectral type has been stablished by Cunha & Lambert (1992) as B0.5V. Ismailov (1988), Cunha & Lambert (1992) and Vitrichenko et al. (2000) have determined effective temperatures for this star in the range 26500 − 29970 K, and gravities ($\log g$) between 3.92 and 4.4 dex.
The only studies found in the literature about HD37023, classified as B0.5V, are those by Ismailov (1988), who obtain $T_{\rm eff} = 20500$ K and $\log g$=3.5, and by Cunha & Lambert (1992, 1994) who use this star to derive stellar abundances in Orion B stars; the parameters derived by this authors are $T_{\rm eff} = 32600$ K and $\log g$=4.70.

To derive the rotational velocity we look for metal lines apparently free of blends; using the FWHM of O II, Si III, Si IV, Mg II and C II lines projected rotational velocities of 56 ± 1 km s^{-1} and 51 ± 1 km s^{-1} are obtained for θ^1Ori A and θ^1Ori D respectively.

Figure 1 shows the fitting of the H I, He I and He II line profiles calculated with FASTWIND to those observed in θ^1Ori A. The parameters derived for this star and θ^1Ori D, as well as their uncertainties, are shown in Table 1. The spectral range observed does not allow us to determine the wind parameters, so we use some characteristic values. For these stars we do not expect emission contamination in the photospheric lines.

Cunha & Lambert (1992, 1994) have obtained abundances of C, N, O and Si for these stars using Kurucz blanketed LTE models. It has been recently shown that non-LTE line blanketed models can strongly affect the derived temperature structure (Martins et al. 2002; Bianchi & García 2002; Herrero et al. 2002), and then the temperature of the region inside the atmosphere in which the metal lines are being formed.
Preliminary results obtained with FASTWIND show the Nitrogen abundance to be consistent with that derived in the nebular and stellar studies by Esteban et al. (1998) and Cunha & Lambert (1992, 1994). The abundances of C and other α elements are being calculated.

3.2. θ^1 *Ori B (HD37021)*

This is the faintest of the four Trapezium stars (V $\sim 8^m$). It is a binary and eclipsing system with a period of 6.47 days (Bondar & Vitrichenko, 1995).

We have compared the spectra obtained in 01/99 ($\phi \sim 0.29$) and 12/02 ($\phi \sim 0.97$). Both show very broad H and He lines due to the high rotational velocity; in the first one no metal lines are distinguished from the noise in the continuum; only the Mg II 4481 line appears in the observed spectral range. From this line a projected rotational velocity $v\sin i \sim 270$ km s^{-1} is determined. We have found, however, that the $v\sin i$ derived from this line in the 12/02 spectrum is ~ 180 km s^{-1}. This could be due to the binarity of the system, as the later spectrum also shows some stronger and narrower metal lines, associated with a possible companion.

3.3. θ^1 *Ori C (HD37022)*

The strange variable spectral features of this star are known since the studies of the He II 4686 inverted P-Cygni profile by Conti (1972). Since then, lots of studies have been done to understand why this star has some variable photospheric and wind lines

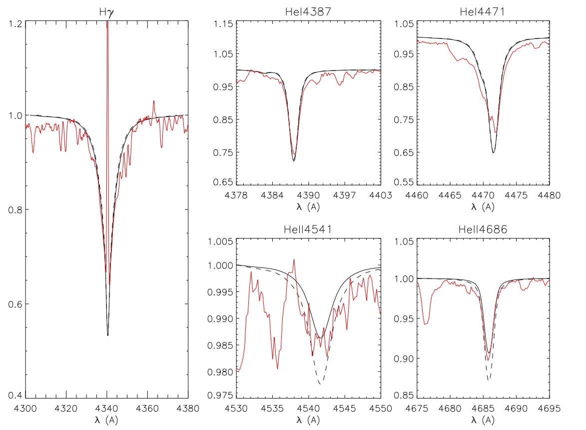

Fig. 1. Fit to the H and He lines of the spectrum of θ^1Ori A. Best fit appears as a solid line ($T_{\rm eff} = 29000$ K, $\log g = 3.9$ dex, $\epsilon = 0.09$, $\xi_t = 10$ km s^{-1}); dashed line corresponds to a model with $T_{\rm eff} = 30000$ K.

in the optical and UV spectrum. The variability period is 15.426 days, consistent with the rotational period as derived from the projected rotational velocity and the model of Howarth & Prinja (1989). Stahl et al. (1996) and Babel & Montmerle (1997) assumed the variability of the star to be associated with a magnetically confined wind. In the model proposed by Babel & Montmerle, the wind is driven by the magnetic field from the pole (inclined 45° from the rotational pole of the star) to the magnetic equator; a cool disk and a hot post-shock region are formed. Recently, Donati et al. (2002) have detected signatures of a dipolar magnetic field; however, the spectropolarimetric observations are in contradiction with the magnetic geometry predicted by Stahl et al. (1996) and used by Babel & Montmerle (1997).

We have studied the optical spectrum of the Orion Nebula ionising star and the variability of some of its spectral features. These are shown in Figure 2. To compare with a normal O7V star we have also considered the spectrum of 15 Mon (HD47839).

By using C III, N IV and Si IV lines, a rotational velocity $v\sin i = 60 \pm 10$ km s^{-1} is derived. Lines of lower ionisation states, like Si III, C II, O II and N II, are found to be very broad (a rotational velocity corresponding to these lines would be 120 ± 10 km s^{-1}). The later do not appear in the spectrum of 15 Mon and do not change with phase in the spectrum of θ^1Ori C.

FASTWIND is a stationary, unified model at-

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TABLE 1

STELLAR PARAMETERS OF θ^1ORI A AND θ^1ORI D [a]

Star	$T_{\rm eff}$ (kK)	$\log g$ (dex)	ϵ	ξ_t (km s^{-1})	R ($R_\odot$)	M ($M_\odot$)	$\log \frac{L}{L_\odot}$
HD37020	29 ± 1	3.9 ± 0.1	0.09	10	$6.3^{+2.4}_{-1.8}$	12^{+11}_{-6}	4.5 ± 0.3
HD37023	30 ± 1	3.8 ± 0.1	0.09	10	$6.2^{+2.3}_{-1.7}$	10^{+9}_{-5}	4.4 ± 0.3

[a]Typical values for the wind parameters have been selected for the analysis ($\dot{M}=10^{-9}$ $M_\odot yr^{-1}$, $v_\infty=1500$ km s^{-1}, $\beta=0.8$). ϵ is the He abundance by number relative to (H + He). ξ_t is the microturbulence.

mosphere code that does not take variability in the model atmosphere into account. As the variable features in the spectrum of θ^1Ori C could be associated with a external structure (e.g. a cool disk in the magnetic equator), we would need to determine what features could be associated with the atmosphere of the star before modeling it by using FASTWIND. Obviously the Balmer lines and He II 4686 are affected by the external structure in phase ~ 0.0, and perhaps in phase ~ 0.6. Other He I and He II lines could be affected as well. We have seen that it is not possible to fit the He I and He II lines in the $\phi \sim 0.6$ spectrum with the same stellar parameters; once the H I and He II lines are fitted, the He I lines appear fainter. We are presently investigating whether the He I lines are affected by the possible external structure and whether it is possible to use the He I / He II ionization equilibrium to determine $T_{\rm eff}$.

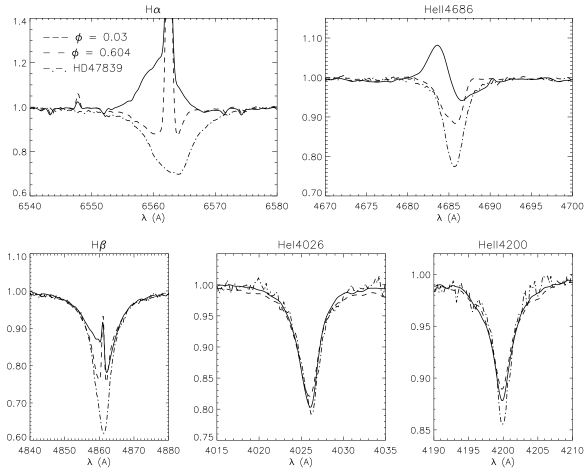

Fig. 2. Variable spectral features appearing in the optical spectrum of θ^1Ori C. The spectrum of HD47839 (15 Mon) is shown for comparation with a normal O7V star.

4. CONCLUSIONS AND WORK IN PROGRESS

The methodology used for the determination of the stellar parameters of θ^1Ori A and D (fit of the synthetic and observed profiles of H and He lines) has allowed us to give more precise values for $T_{\rm eff}$ and $\log g$ than previous studies, based on empirical calibrations or use of equivalent widths. We have also used more realistic hyphotesis for the modeling the stellar atmospheres (sphericity and non-LTE line blanketing). Once the stellar parameters have been stabished we will analyse the spectrum of the two B0.5V Orion stars for a chemical study of their atmospheres. The C, N, O, Si and Mg abundances obtained will be compared with those of nebular studies (Esteban et al. 1998) and previous stellar studies (Cunha & Lambert 1992, 1994).

More work is needed to understand the nature of θ^1 Ori C before we can apply spherically symmetric mass losing models to derive the stellar parameters and ionising flux distribution of the Orion Nebula ionising star.

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