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A NIR spectral sequence of O-type supergiants

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Resumen / El estudio de la morfología espectral es una herramienta poderosa para comprender las propiedades fundamentales de las estrellas. El esquema de clasificación espectral para las estrellas O se revisó y se propuso un nuevo conjunto de estrellas estándar espectrales para todos los subtipos entre O2 y B0 y para todas las clases de luminosidad. Estamos trabajando en la construcción de un atlas espectral con observaciones de alta calidad entre $0.85 - 2.5$ μm. Las observaciones para este proyecto se iniciaron hace siete años y se realizan con los espectrógrafos GNIRS (Observatorio Gemini) y FIRE (Observatorio Las Campanas). Presentamos aquí un segundo lote de resultados, que incluye los espectros de una secuencia de temperatura completa de estrellas estándar supergigantes en las bandas J, H y K. Del análisis de los datos se desprende que es posible definir criterios de clasificación espectral utilizando líneas de He I y He II presentes en los mismos.

Abstract / The study of spectral morphology is a powerful tool for understanding the fundamental properties of stars. The spectral classification scheme for O stars was revisited and a new set of spectral standard stars was proposed for all sub-types between O2 and B0 and for all luminosity classes. We are working on the construction of a spectral atlas with high quality observations between $0.85 - 2.5$ μm. Observations for this project have begun seven years ago, and they are carried out with the GNIRS (Gemini Observatory) and FIRE (Las Campanas Observatory) spectrographs. We present here a second batch of results, including the spectra of a complete temperature sequence of supergiant standard stars in the J, H and K-bands. The analysis of this data set implies that it is possible to define spectral classification criteria using the He I and He II lines present in it.

Keywords / atlases — stars: early-type — stars: massive

1. Introduction

O stars, although few in number, play an important role in the energetic, dynamical and chemical evolution of their galactic environment due to the influence of their powerful UV radiation, strong stellar winds and explosive deaths. In most cases, their lives are too short to allow them to blow away the dust and gas cocoon that gave them birth. This hampers their observation in the optical domain, and thus observations at infrared wavelengths are needed. In addition, O stars are concentrated towards the Galactic plane, where large amounts of dust produce high levels of optical extinction, precluding optical observations of relatively distant objects. Several NIR atlases of OB stars have been published since the ‘90s, they used to be wavelength limited or constructed with low resolution or low signal-to-noise ratio spectra or without a complete sample of classification standards (cf. Torres Robledo et al., 2011). The need for a modern NIR atlas of OB stars became more evident when a new grid of standard stars was defined by the Galactic O-Star Spectroscopic Survey (GOSSS; Sota et al., 2011, 2014; Maíz Apellániz et al., 2016). To improve this situation, we began collecting high-resolution NIR spectra of the newly defined GOSSS standards in order to build a new atlas.

2. Observations

NIR spectra of a set of O-type supergiant stars were secured by means of the Gemini North Infrared Spectrograph (GNIRS)* and the Folded-port InfraRed Echellette (FIRE) attached at the Magellan Baade 6.5 m telescope at Las Campanas Observatory, Chile.

GNIRS covers a spectral range from 0.8 to 5.4 μm with a resolving power $R \sim$17000 to 17800. We used the 110.5 mm^{-1} grating with the long blue camera and a 0.10 arcsec slit in cross-dispersed mode. To ensure a complete wavelength coverage, we must observe ten equally spaced central wavelengths of the cross-disperser for each star. FIRE was used in high-resolution echellette mode, with a slit width of 0.6 arcsec. The spectral coverage is 0.85 to 2.5 μm at $R = 6000$.

In both cases, telluric standard star spectra were also taken for flux calibration and telluric absorption correction. Ar (GNIRS) and ThAr (FIRE) lamp spectra were taken for wavelength calibration.

The reduction of the GNIRS data was made with the IRAF tasks provided by the Gemini Observatory. On the other hand, the FIRE data were reduced using the IDL pipeline FIREHOSE kindly provided by the instrument developer (Simcoe et al., 2013). At Giudici Michilini et al. (2020) can be found some additional information

*Program IDs: GN-2013B-Q-84 and GN-2016A-Q-91.

about the data reduction.

3. Results

We obtained the NIR spectra of the following standard stars (Maíz Apellániz et al., 2016): HD 93129 AaAb (O2 If*), Schulte 7 (O3 If*), HD 15570 (O4 If), CPD -47 2963 AB (O5 Ifc), HD 163758 (O6.5 Iafp), HD 193514 (O7 Ib(f)), HD 156154 (O7.5 Ib(f)), HD 151804 (O8 Iaf), HD 125241 (O8.5 Ib(f)), and HD 154368 (O9.2 Iab), which represent a temperature sequence among O-type supergiants.

Taking into account that this study will compare the behavior of the NIR features with the ones in the optical range, we measured the equivalent width (EW) of several features which are present in most spectra. They were measured with the SPLOT routine in IRAF-ONEDSPEC. Errors were estimated from multiple measurements of the same profile, yielding values smaller than 10 %. These measurements are presented in Figs. 1 and 2, where we colored the lines according to their location in the different bands: J (blue), H (green), or K (red). Obtained spectra are shown in Fig. 3.

Regarding the temperature sequence, in general He I lines clearly become stronger as temperature decreases (except He I $\lambda1.083$ μm which appears in emission but without an apparent correlation). On the other hand, He II seems to be poorly sensitive to temperature (except He II $\lambda1.012$ μm which appears in emission in the earliest types). In turn, two emission lines: C IV $\lambda2.078$ μm and N III $\lambda2.115$ μm present a very interesting behavior. C IV $\lambda2.078$ μm is apparently absent at O2 and in absorption at O3, then increases its EW from O4 to O6.5 to finally decrease towards O9.2. N III $\lambda2.115$ μm starts off as a faint emission at O2 and keeps increasing until O6.5, then from O7 to O9.2 drops to become a faint emission again.

As some of these standards were already observed, we compared our spectra with the ones in Hanson et al. (2005). During this task we found a different profile of Brγ in the spectra of HD 15570 (see Fig. 6 in Hanson et al., 2005). Such kind of variable features were reported in the optical: Hα and Hβ and He II $\lambda0.4686$ μm lines by (De Becker et al., 2009). Thus, this fact will be studied in future works.

We also consider the behaviour of He II $\lambda1.012$ μm, which is in emission between the subtypes O2 and O5 but its "optical counterpart", He II 0.4686 μm, is present in emission in a wider range, from O2 to O6.5 (and marginal, around O8 standard stars) as can be noted in Sota et al. (2011).

4. Conclusions

We obtained high resolution NIR spectra of a set of O-type supergiant classification standard stars in order to analyse the temperature effects at this luminosity class. As expected, He I lines become stronger as temperature decreases, but He II seem to be less sensitive to temperature. EW ratios of He I and He II can help the spectral classification.

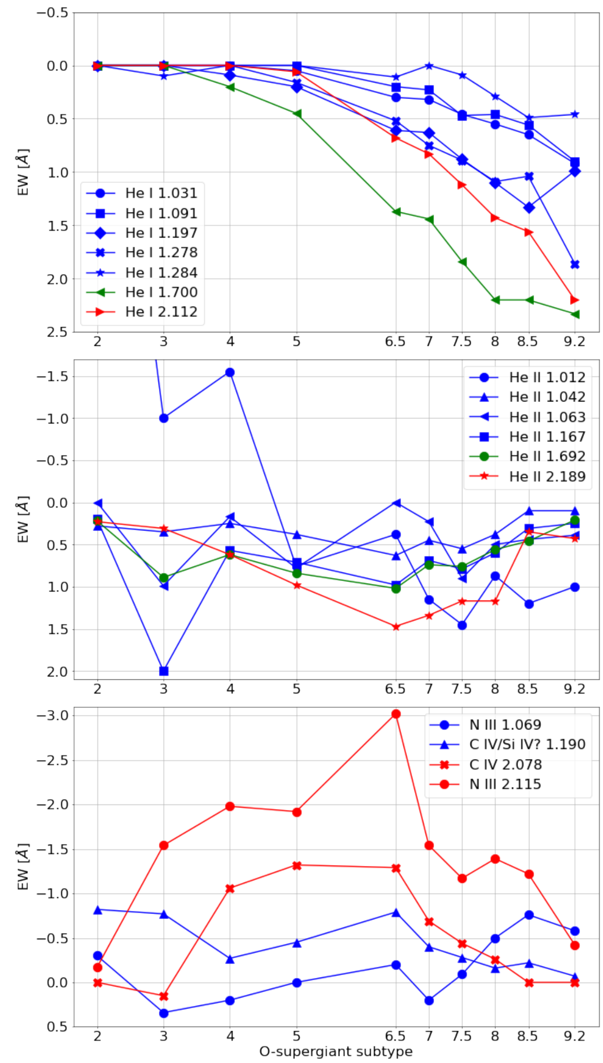

Figure 1: EW of different lines measured in the spectra of the standard stars. The EW measurement of He II $\lambda1.012$ μm in the spectrum of HD 93129 AaAb lies outside the boundaries of the plot ($EW = -7$ Å). The lines are colored according to their location in the different bands: J (blue), H (green), or K (red).

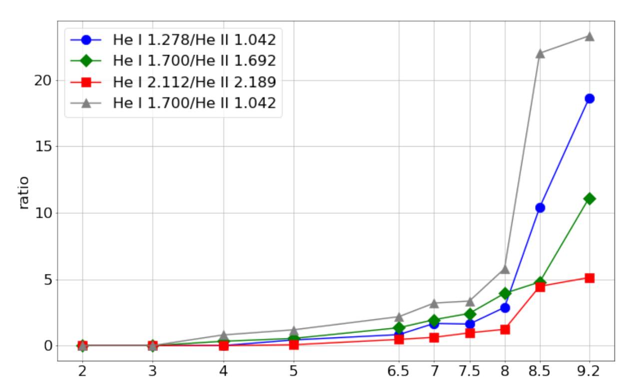

Figure 2: He I/He II line ratios. The colors are as in Fig. 1 except for the grey symbols which correspond to He I 1.700/He II 1.042.

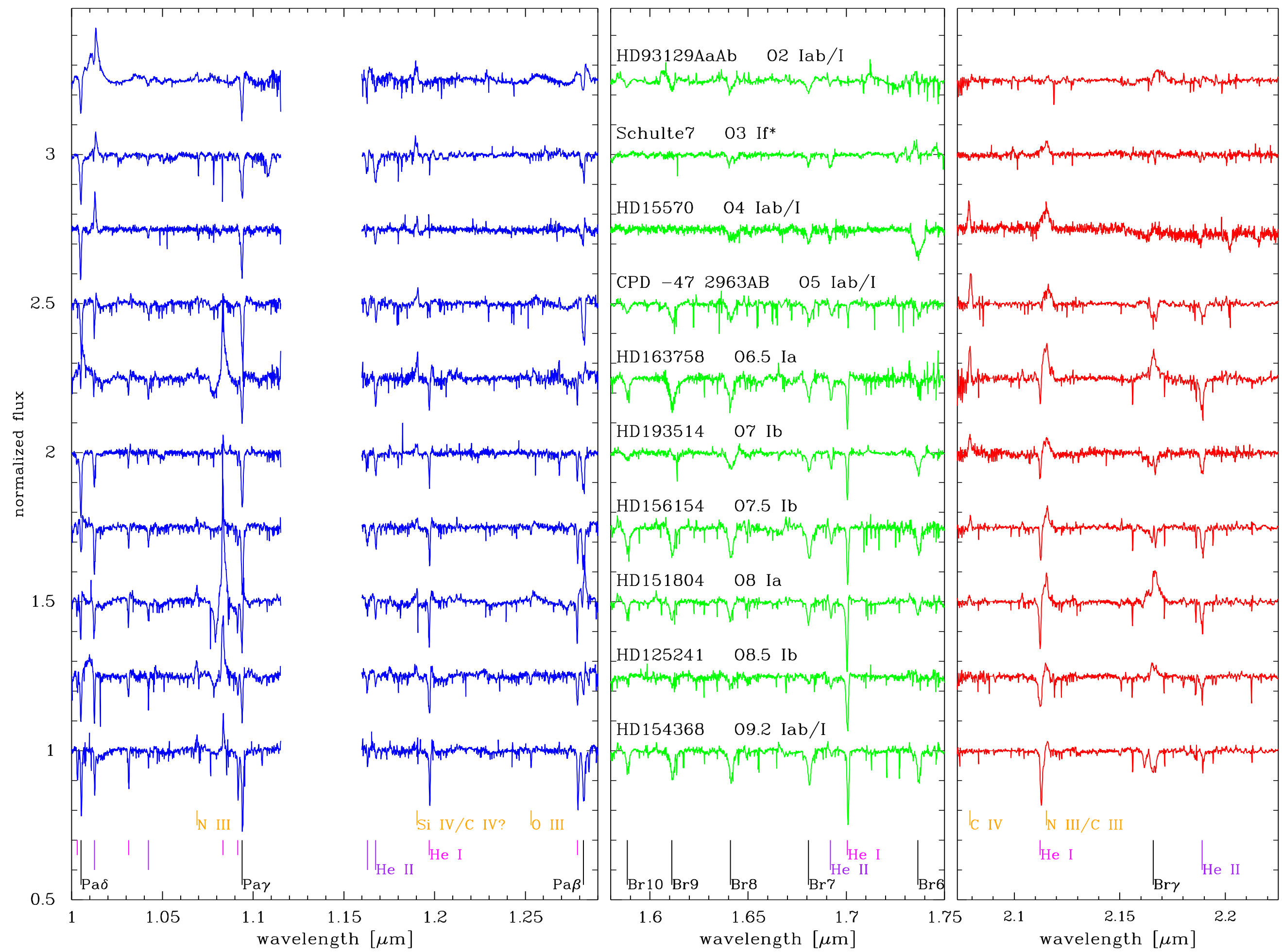

Figure 3: NIR sequence of O-type supergiant standards. Lines of He I and He II are labeled with pink (short lines) and violet (long lines), respectively.

Figure 2 compares the values obtained considering different lines in each band. The three bands include both ionization states of He that can be used to classify. But it is evident that the ratio between the He I 1.700 (in H band) and He II 1.042 (in J) is the most suitable.

Besides, C IV $\lambda 2.078$ μm and N III $\lambda 2.115$ μm present in the K-band show an useful behavior to be added to the He I/He II ratio.

We will continue completing the grid of standards to finally construct a high-resolution Atlas for spectral classification of O-type stars in the NIR. We also plan to compare the NIR criteria with the optical ones.

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