Luminosity effects in O4-type stars in the near infrared domain

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Resumen / El estudio de la morfología espectral es una poderosa herramienta para inferir las propiedades fundamentales de las estrellas. El esquema de clasificación espectral de estrellas O fue recientemente revisado, proponiéndose un nuevo conjunto de estrellas estándares para todos los subtipos desde O2 hasta B0 y todas las clases de luminosidad. Dado que la mayoría de las estrellas O Galácticas se encuentran en regiones donde la absorción interestelar en las bandas ópticas es muy alta, es necesario extender este atlas de estándares a las longitudes de onda del infrarrojo cercano. Hace cuatro años hemos comenzado con la obtención de datos con el objeto de construir un atlas espectral de alta calidad en el infrarrojo cercano ($0.85 - 2.5\,\mu$m). Las observaciones fueron llevadas a cabo con los espectrógrafos GNIRS (Gemini Norte, Hawaii) y FIRE (Las Campanas, Chile). Aquí presentamos nuestros primeros resultados que incluyen una comparación entre los espectros en las bandas Y y J de cuatro estrellas estándares de tipo espectral O4 y diferentes clases de luminosidad. Las bandas antes mencionadas se muestran potencialmente adecuadas para el desarrollo de criterios de clasificación espectral. La línea He II $\lambda 1.012$ μm allí ubicada permitiría distinguir diferentes clases de luminosidad.

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 recently revised and a new set of spectroscopic standard stars was proposed for all subtypes from O2 to B0, and for all luminosity classes. Given that the vast majority of the Galactic O stars lie in regions where the interstellar absorption in the optical bands is very high, it is necessary to extend the atlas to wavelengths in the near infrared (NIR). Four years ago, we started to gather data in order to build a spectroscopic atlas of high-quality observations in the NIR ($0.85 - 2.5\,\mu$m). The observations were carried out with the GNIRS (Gemini North, Hawaii) and FIRE (Las Campanas, Chile) spectrographs. We present here our first results that include a comparison among the spectra of four O4 type standard stars of different luminosity classes in the NIR Y and J-bands. The aforementioned bands are potentially suitable for the development of spectral classification criteria. The line He II $\lambda 1.012$ μm located there would allow us to make luminosity class classification.

Keywords / stars: early-type — stars: massive

1. Introduction

O stars, although few in number, are objects of great importance. They dominate the energetic, chemical, and dynamic evolution of the environment where they live. Their extremely high output of ionizing UV radiation, strong winds, and explosive deaths alter chemically and dynamically the interstellar medium at galactic scales. However their life is short and during the early phases most of them are shrouded by the gas and dust cocoon that gave them birth. This renders them very hard to observe in the optical regime so it is necessary to observe them in the infrared domain (IR). Moreover, the interstellar dust concentration on the Galactic Plane disfavors the observation of distant stars in the optical regime, because of the high extinction. Again, the opportunity to observe these objects is opened in the NIR.

The first NIR spectral atlas of stars was presented by Lancon & Rocca-Volmerange (1992). Numerous NIR atlases of OB stars have been published since that time (see Ivanov et al., 2004, and references therein). Hanson et al. (2005) published a NIR spectral atlas of O and early-B stars, covering limited set of spectral types in H- and K-bands, with high resolution (R $\sim 8\,000 - 12\,000$) and high signal-to-noise ratio ($S/N \sim 100{-}300$). No further atlas with better resolution, and similar or greater spectral coverage in these bands was presented since then. There is also a lack of high resolution spectra in J, H, K, L and M-bands for OB stars of known spectral types (cf. Torres Robledo et al., 2011).

The spectral classification criteria for O-stars in the optical range were recently improved, and a carefully designed atlas of spectral standards was presented through the Galactic O-Star Spectroscopic Survey (GOSSS) (Sota et al., 2011, 2014; Maíz Apellániz et al., 2016), superseding the invaluable effort led by Nolan R. Walborn (1944–2018) through his scientific career (see e.g. Walborn, 1971; Walborn & Fitzpatrick, 1990). Therefore, we began collecting high-resolution NIR spectra in order to build an atlas for the new grid of standard stars.

In this paper, we show our preliminary results concerning to the Y- and J-band spectra of four O4 stars. This is the hottest sub-type having the most complete luminosity sequence in the new optical classification scheme and thus allows a thorough analysis of the spectral features related to the luminosity classes.

2. Observations

2.1. The GNIRS spectra

The Gemini North Infrared Spectrograph (GNIRS) is a multi-function spectrograph able to cover the spectral range from 0.8 to 5.4 μm. It can provide low, medium, and high resolution spectra with its four different camera options: “long” and “short” focal lengths combined with a “blue” and “red” wavelength selection.

The data presented here were obtained during the nights of April 19 and October 30, 2013. We used the 110.5 mm^{-1} grating with the long blue camera and a 0.10 arcsec slit in cross dispersion mode. With this configuration a resolving power of $\sim$ 17000 to $\sim$ 17800 is reached in the bands Y, J, H and K. To ensure a complete coverage, and optimize the total exposure time, a cross-disperser was employed with ten equally spaced central wavelengths. A standard ABBA nodding sequence was employed to perform the sky substraction with the target on the slit all the time. Telluric standard star spectra were also taken for flux calibration and telluric absorption correction. Argon lamp spectra were taken for wavelength calibration. The reduction of the data was made with the IRAF tasks provided by the Gemini Observatory. Every order of the spectra have been calibrated and corrected separately due to the heterogeneity of the telluric absorption.

2.2. The FIRE spectra

The Folded-port InfraRed Echellette (FIRE) is a spectrometer installed at the Magellan Baade 6.5-m telescope at Las Campanas Observatory, Chile. It offers high and low resolution modes capable of covering the complete NIR range in one exposure.

We used FIRE during the night of June 3, 2017, in high-resolution echelette mode, with a slit width of 0.6 arcsec. Again, a standard ABBA nodding sequence was employed, keeping the target on the slit. Sky flats and lamp flats were taken, for determination of the location of each order in the detector and flat field correction, respectively. All the spectra were read in Fowler 1 mode. Thorium-Argon lamp spectra were acquired after each observation for wavelength calibration. A0 V-type stars were observed immediately after scientific target stars to perform telluric correction. The data were reduced using the IDL pipeline FIREHOSE (Simcoe et al., 2013), specifically designed for the reduction of FIRE data.

3. Analysis of the spectra

We present the Y- and J-band spectra of four standard stars defined in Maíz Apellániz et al. (2016): HD 46223, O4 V((f)), and HD 15570, O4 If, both observed with GNIRS, and HD 93250, O4 IV(fc), and HD 96715, O4 V((f))z, both observed with FIRE. This set of spectra represents the luminosity class sequence for the O4 spectral type.

In Fig. 1, we present the spectral region $\sim$ 0.89 μm and 1.35 μm for the four observed targets. We could identify several lines using the atomic spectral line list of Hirata & Horaguchi (1994): hydrogen lines of Paschen series, such as Pa10 λ0.901 μm, Pa9 λ0.922 μm, Paϵ λ0.954 μm, Paδ λ1.005 μm, Paγ λ1.093 μm, Paβ λ1.281 μm. The observed He lines are He II λ1.012 μm, λ1.042 μm, and λ1.162 μm, He I λ1.279 μm and λ1.284 μm. We also identified a few metallic lines: N III λ0.934 μm, N V λ1.167 μm, and C IV λ1.190 μm.

We point out the non-detection of stellar He I λ1.083 μm in our spectra. This line is supposed to be formed in the wind and thus it is considered sensible to its physical properties (see e.g. Groh et al., 2007). Andrillat & Vreux (1979) found this line is present in O5-9 stars, but absent in the spectra of three O4 stars (including HD 15570 and HD 46223). Just in one of them, HD 16691, it was found variable. However, in our spectra of HD 15570, HD 46223, and HD 93250 we detect a narrow absorption line, which we identified as interstellar (or circumstellar) He I λ1.083 μm. The production of metastable helium in the interstellar gas was predicted by Scherb (1968) and its presence was also reported toward other massive stars embedded in HII regions (Nazé et al., 2019).

In Fig. 2, we show the equivalent width (EW) measurements obtained for the He II λ1.012 μm (blue circles) and λ0.4686 μm (purple squares) lines in our NIR and optical spectra (found in GOSSS) respectively. We must recall that the ”z” phenomenon distinguished in the luminosity class V is quantified by Arias et al. (2016), which is added when the He II λ0.4686 μm line is 1.1 times stronger than He II λ0.4542 μm or He I λ0.4471 μm. Meanwhile, the specific standards for the Vz sub-class are given by Maíz Apellániz et al. (2016).

The EWs measured in these four spectra present a progression similar to that observed in the optical line of HeII in λ0.4686 μm (also included in the Fig. 2), whose upper level coincides with the lower level of HeII λ1.012 μm. The mentioned optical line is a primary luminosity classification criterion (see Sota et al., 2011, 2014) which leads us to explore the possibility of using this infrared He II line in the same way. Previous works discussed this behaviour along temperatures but none were conclusive (see e.g. Mihalas & Lockwood, 1972; Vreux & Andrillat, 1979a,b; Conti & Howarth, 1999).

4. Conclusions

In this work we propose to explore the possibility of using He IIλ1.012 μm as a quantitative luminosity criterion. This demonstrates the importance of the Y and J-band for the spectral classification in the IR.

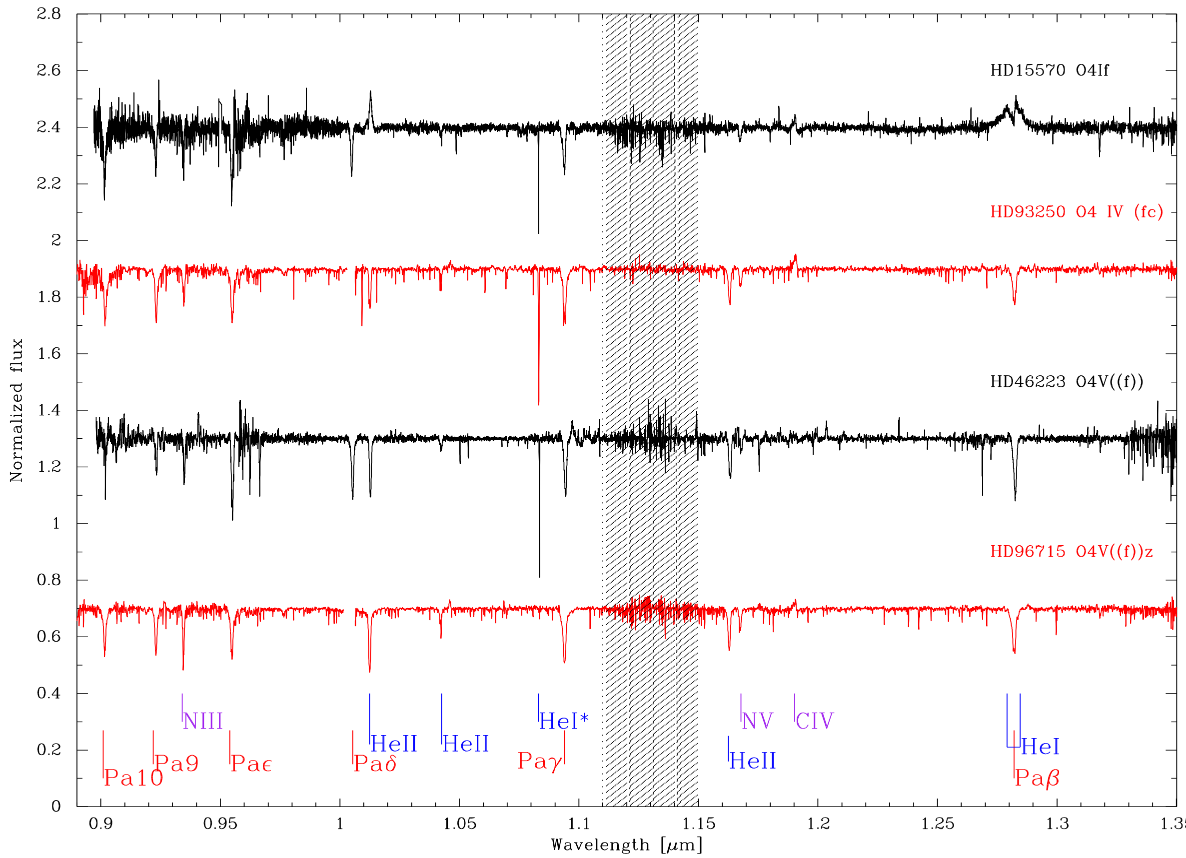

Figure 1: GNIRS (black) and FIRE (red) spectra in the $0.89-1.35\,\mu$m range of the four O4 stars. The most characteristic luminosity discriminator is the He II $1.012\,\mu$m line which changes from emission in the supergiant to absorption in the dwarf. Paδ in the FIRE spectra is affected by a reduction artifact and thus it was excluded from this figure. The asterisk $(*)$ denotes a line identified as interstellar (or circumstellar).

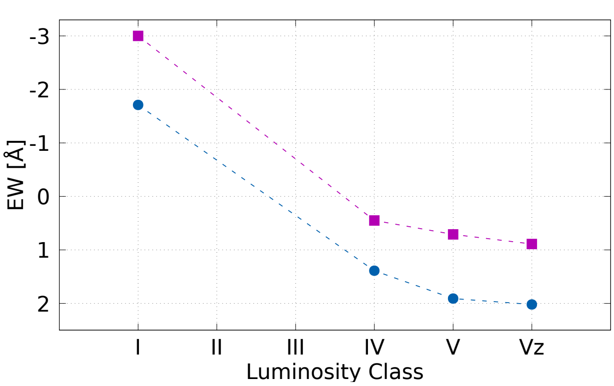

Figure 2: Behaviour of the He II $\lambda1.012$ μm (blue circles) and $\lambda0.4686$ μm (purple squares) equivalent widths. The *EW* axis is inverted to highlight the emission nature of this line in the luminosity class I.

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