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Flamingos-2 spectroscopy of early-type peculiar stars

M. L. Arias[1], A. F. Torres[1], M. Kraus[2], & L. Cidale[1]

[1] *Facultad de Ciencias Astronómicas y Geofísicas, UNLP and IALP (CONICET-UNLP), La Plata, Argentina*
[2] *Astronomical Institute, Czech Academy of Sciences, Fričova 298, 251 65 Ondřejov, Czech Republic*

Contact / editor.baaa@gmail.com

Resumen / En este trabajo presentamos las primeras observaciones espectroscópicas en la región del infrarrojo cercano, para cuatro estrellas tipo B con líneas en emisión. Todas ellas son candidatas a objetos con fenómeno B[e] cuyo estado evolutivo no ha podido ser aún establecido. En base al análisis de estas observaciones, describimos las principales características de cada espectro, derivamos propiedades del material circunestelar y discutimos su posible naturaleza.

Abstract / We present the first near-infrared spectroscopic observations of four southern Galactic early-type emission-line stars. All objects are B[e] candidates with yet unclear evolutionary state. Based on the analysis of these observations, we describe their main spectral features, derive properties of their circumstellar material, and discuss on their possible nature.

Keywords / (stars:) circumstellar matter, stars: early-type

1. Introduction

During the post-main sequence evolution, massive stars undergo short phases characterized by strong, often eruptive mass-loss episodes. As a consequence, these stars are deeply embedded in shells, nebulae, or disks, which are cool and dense, and give rise to a complex chemistry, producing molecules and dust. Furthermore, many of these rare objects display complex spectra in which photospheric features are veiled by the circumstellar envelope, making it difficult to assign them proper spectral types and evolutionary stages. However, assessing the composition and geometry of their ejecta provides important keys to help disentangling their nature. To contribute to the study of the circumstellar material and get clues on the nature of the central objects, we started building a near infrared spectroscopic database of massive stars in such transition phases (see Arias et al., 2018). In this work, we describe the medium resolution spectra obtained with GEMINI/FLAMINGOS-2 (F2) spectrograph for a sample of four poorly studied southern B-type objects.

2. Observations

We performed spectroscopic observations in the range 1.9-2.5 μm using the F2 spectrograph in longslit mode, with the 0.18"/pix camera, the 2 pixels slit, the R3K disperser and the K-long filter. This configuration provides a resolving power around 3000. The observations were acquired under the programs GS-2018A-Q-401 and GS-2019A-Q-419 and reduced using standard tools.

3. Results

The selected sample consists of four poorly studied southern early-type stars.For all objects, we present the first near-infrared K-band spectra. These were normalized to the continuum and are shown in Fig. 1. Identified lines are marked within the spectra and listed in Table 1, along with their laboratory wavelengths and profile characterizations. In what follows we describe in detail each individual object, presenting, if were possible, our analysis of the infrared spectra, and discuss our results.

WRAY 15-1651 (J2000 α=17:14:45, δ=-36:18:38)
This is an extreme emission-line star with huge infrared excess, lacking accurate spectral classification. Its spectral type possibly ranges between B1 and B5, but the optical spectrum is strongly veiled, and the absence of absorption lines prevents to constrain the luminosity class. Its optical spectrum shows very strong emission of Hα and of the forbidden lines [O I], [S II], [N II] and [Ca II] (Carmona et al., 2010).

Our K-band spectrum shown in Fig. 1 is the first near infrared spectrum of this star. Hydrogen lines are seen in emission, being Brγ and Brδ the strongest features. Some Fe II emission lines as well as weak emissions in Mg II and Na I are observed.

Remarkable are also the intense CO molecular emission band heads detected in the 2.3–3.5 μm region, superimposed on weak emission of the hydrogen Pfund series. These molecular bands indicate a cool and dense circumstellar region and usually trace the inner rim of a molecular disk as seen in many B[e] supergiants and pre-main sequence objects. Using the codes developed by Kraus et al. (2000) and Kraus (2009) we modeled the emission of both the Pfund series and the CO molecular band heads to derive properties of their forming region.

The Pfund lines are assumed to be optically thin and are computed according to Menzel case B recombination. Their line profiles appear single peaked and can be reproduced with a Gaussian profile with velocities $130 \pm 10\,\mathrm{km\,s^{-1}}$ and a gas temperature of 10^4 K. We also derived a hydrogen density of $1.7 \times 10^{12}\,\mathrm{cm^{-3}}$ within the respective line-forming region. For the calculations of the molecular emission spectrum local thermodynamic equilibrium was assumed and ^{12}CO as well as the ^{13}CO isotope were considered. The best fitting model shown in Fig. 2 was achieved for a molecular gas temperature $T_{\mathrm{CO}} = 2200 \pm 100\,\mathrm{K}$ and a column density of $N_{\mathrm{CO}} = (4 \pm 1) \times 10^{21}\,\mathrm{cm^{-2}}$. The emission is assumed to originate from a ring with a rotational velocity $v_{\mathrm{rot}} = 150 \pm 10\,\mathrm{km\,s^{-1}}$.

The spectrum shows no indication for ^{13}CO enrichment (Kraus, 2009). This points towards an unevolved nature, being in agreement with either a Herbig Be star or a star just evolving into a supergiant. The 2MASS colors provide no help for classification, as they place the star right at the border between the Herbig Ae/Be stars and the B[e] supergiants in the near-infrared color-color diagram of Kraus (2019). Hence, the true nature of WRAY 15-1651 remains unclear.

Hen 3-938 (J2000 α=13:52:43, δ=-63:32:49)
This is a poorly-studied emission-line star of still unclear nature. It was catalogued as a pre-main sequence star in the Pico dos Dias Survey (PDS) (Sartori et al., 2010). However, this catalog was found to be contaminated by post-AGB stars. Moreover, the observed optical characteristics of this object do not allow to distinguish between a pre-main sequence or a post-AGB star (Vieira et al., 2011). Recently, Condori et al. (2019) classified Hen 3-938 as either a luminous Herbig Be star or a B[e] supergiant based on their high-resolution optical spectra, and Kraus (2019) reached the same conclusion when inspecting the star's infrared colors.

The near infrared spectrum (Fig. 1) displays Brγ, Brδ and the Pfund series in emission. Emission features in Mg II, Na I, and a few Fe II lines are also observed. As its optical counterparts (Condori et al., 2019), the near-infrared He I line at 2.05 μm shows a P Cygni profile, giving evidence of a wind. There is no clear indication of molecular CO emission or absorption. In total, the near-infrared spectrum resembles very much that of a typical LBV in quiescence or a B[e] supergiant without CO (e.g., Oksala et al., 2013). While its infrared colors and its too low luminosity exclude an LBV status of the object, an evolved nature seems to be plausible.

[GKF2010] MN 13 (J2000 α=13:42:33, δ=-62:48:11)
Spitzer 24μm images revealed the presence of a bipolar nebulae around this star, similar to the ones around the WNL star WR 124 and the LBV candidate HD 168625 (Gvaramadze et al., 2010). This similarity suggests that the nebula of MN 13 is probably the product of post-main sequence evolution of a massive central star.

The infrared spectrum shown in Fig. 1 displays hydrogen lines of the Brackett and Pfund series in emission. The He I line at 2.05 μm is in strong emission.

Table 1: Line identification in the infrared spectra of the program stars.

Element λ [μm]	WRAY 15-1651	Hen 3-938	[GKF2010] MN 13	[GKF2010] MN 44
Fe II 1.938	–	–	em	em
Brδ 1.945	em	em	em	em
Fe II 1.955			em	em
Fe II 1.976	em	em	em	em
Fe II 2.000	–	–	em	em
Fe II 2.005	–	–	–	em
Fe II 2.015	–	–	–	em
Fe II 2.054	–	–	–	em
He I 2.05	em 2p	em Pcyg	em	em
[Fe II]? 2.046	–	–	em	–
Fe II 2.089	em	em	em	em
He I 2.113	–	–	–	abs
Fe II 2.118	–	–	–	em
[Fe II] 2.134	–	–	–	em
Mg II 2.138	w em	em	em	em
Mg II 2.147	w em	em	em	em
[Fe III] 2.145	–	–	em	–
Na I 2.206	w em	em	–	w em
Na I 2.208	w em	em	–	w em
Brγ 2.166	em	em	em	em
He I 2.185	–	–	–	abs
[Fe III] 2.222	–	–	em	–
[Fe II] 2.225	–	–	em	em
Fe II 2.243	–	–	em	em
[Ni II]? 2.308	–	–	–	em
[Fe III] 2.349	–	–	em	–
Mg II 2.405	–	–	–	em
Mg II 2.413	–	–	–	em
12CO	em	–	–	–
Pfund series	em	em	w em?	em

Notes: em = emission, w em = weak emission, abs = absorption, 2p = double-peaked, Pcyg = P Cygni profile.

Many Fe II and [Fe II] emission lines as well as Mg II lines are present. [Fe III] emission is observed as well. The latter was also detected in the spectrum of the evolved star MWC 349A (Kraus et al., in preparation). The intense emission in both the He I and [Fe III] lines suggests a hot central ionizing star, but the proper classification of this object remains elusive.

[GKF2010] MN 44 (J2000 α=16:32:40, δ=-49:42:14)
Observations with the Spitzer Space Telescope revealed a circular shell around this star, which was taken as evidence that the central object could be an evolved massive star candidate (Gvaramadze et al., 2010).

Recently Gvaramadze et al. (2015) presented follow-up spectroscopic and photometric observations. They showed that the star displayed a rich emission spectrum characteristic of LBVs near the visual maximum back in 2009, whereas He I lines appeared in spectra taken six years later, indicating a higher stellar temperature. Based on this spectral behavior and the recorded variability in stellar brightness that resembles an S Dor cycle, these authors classified the star as bona fide LBV.

Our near-infrared observations of this object is included in Fig. 1. MN 44 displays the richest emission-line spectrum of our four sample stars. The spectrum shows emission lines of hydrogen and Mg II, as well as numerous emission lines of Fe II. He I is seen in emission at 2.05 μm and in absorption at 2.113 μm and 2.185 μm.

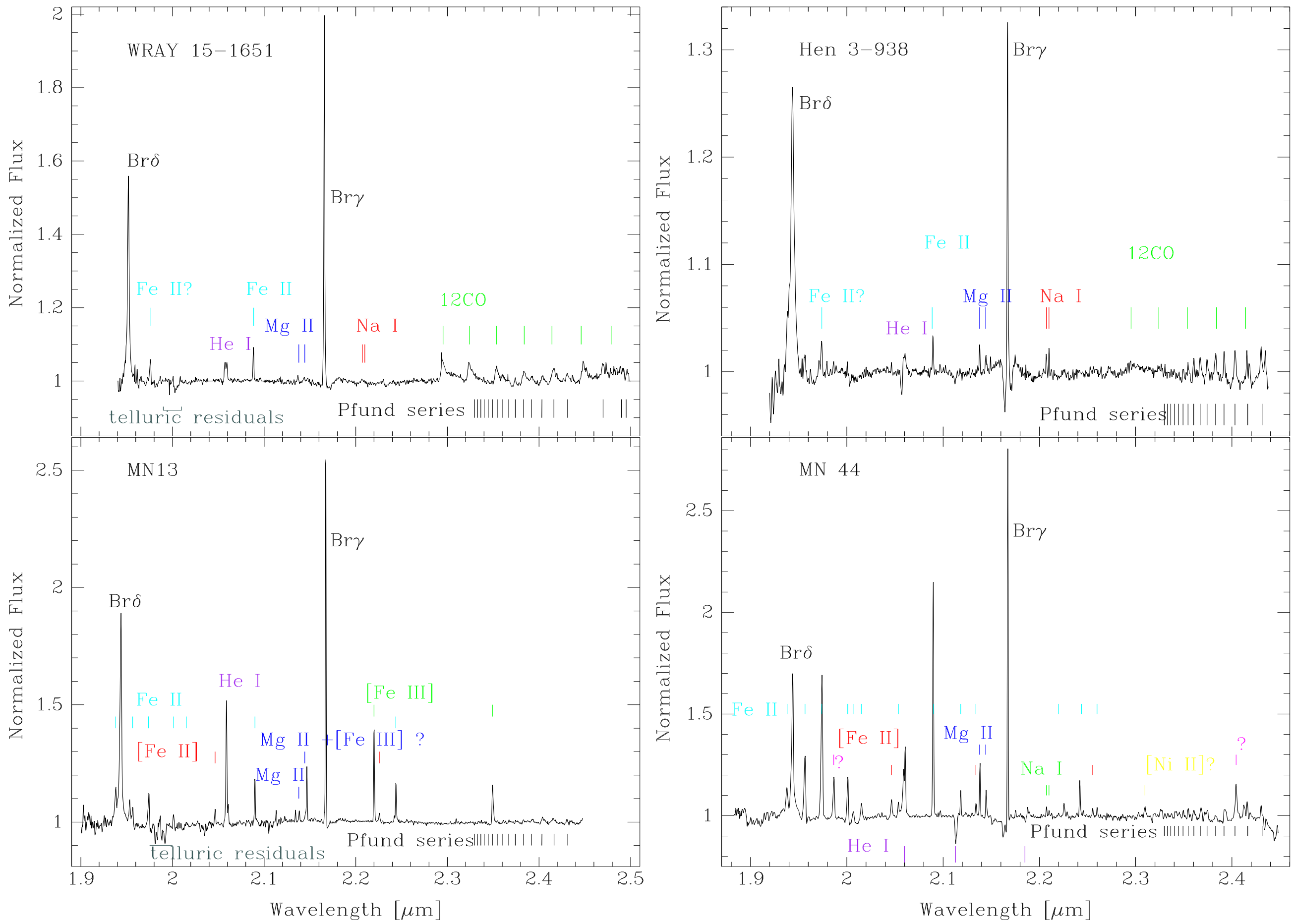

Figure 1: Normalized F2 near-infrared spectra of the four objects. Prominent spectral features are marked and identified.

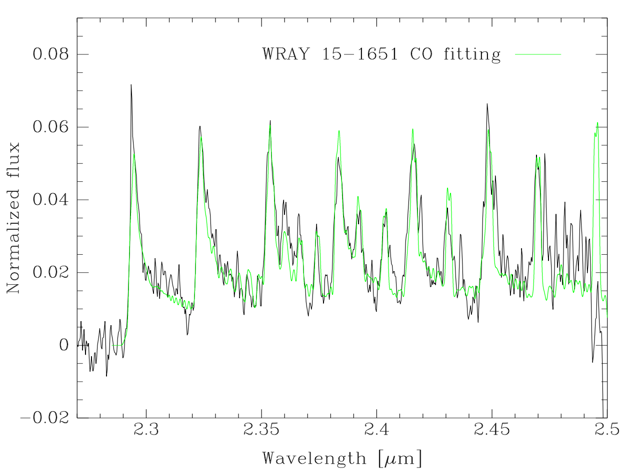

Figure 2: WRAY 15-1651: model fitting (green) to the observed (black) red spectral portion displaying CO band head and Pfund line emission.

The spectrum compares well with K-band spectra of LBVs in quiescence (Oksala et al., 2013). Moreover, the 2MASS near-infrared colors of MN 44 displace the star from the region populated by LBVs in the color-color diagram of Kraus (2019) exactly along the reddening vector for a visual extinction $A_V > 6$ mag, supporting the classification of MN 44 as a highly reddened LBV.

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