Near-infrared characterization of evolved massive stars in M31 and M33

Michaela Kraus[1], María Laura Arias[2,3], Andrea F. Torres[2,3], Michalis Kourniotis[1], Lydia Cidale[2,3]

[1] Astronomical Institute, Czech Academy of Sciences, Ondřejov, Czech Republic
[2] Facultad de Ciencias Astronómicas y Geofísicas, UNLP, La Plata, Argentina [3] Instituto de Astrofísica de La Plata, Argentina

michaela.kraus@asu.cas.cz

1. Motivation

Massive stars are the cornerstone to the dynamical and chemical evolution of their host galaxies. With their intense winds and outbursts, they enrich their environment with processed material and inject large amounts of energy into it. But the evolution of massive stars and the possible (or plausible) evolutionary connections between observed classes of objects (e.g. Luminous Blue Variables, α Cygni variables, B[e] supergiants, warm or yellow hypergiants) are still far from being firmly settled. One major hindrance is that, for the unambiguous classification of evolved massive stars, knowledge about their entire spectral characteristics and long-term photometric variability is essential. In this work, we present new near-infrared medium-resolution K-band spectra for a sample of seven evolved massive stars in M31 and M33, obtained with the Gemini Near-Infrared Spectrograph (GNIRS) at the Gemini North telescope. The detected spectral features are used to characterize the objects and their environments and help to resolve ambiguities of their classification.

2. Target selection

We have selected four objects in M31 and three in M33 with ambiguous classification. These objects were previously classified as LBV candidates (cLBV), iron stars (FeII), B[e] supergiants (B[e]SG) or warm hypergiants (WHG), based on studies of their optical spectral characteristics, photometric variability, and spectral energy distribution (Table 1).

Galaxy	Object LGGS	V [mag]	K_s [mag]	Literature Classification	Ref	New Classification
M31	J004229.87+410551.8	18.80	13.90	cLBV / FeII / B[e]SG	[1/2/3]	LBV in outburst
M31	J004415.00+420156.2	22.73	14.54	cLBV / FeII / B[e]SG	[1/2/3]	B[e]SG
M31	J004320.97+414039.6	19.22	15.20	cLBV / FeII / B[e]SG	[4/2/3]	B[e]SG
M31	J004621.08+421308.2	18.16	15.15	cLBV / WHG	[4/5]	B[e]SG
M33	J013242.26+302114.1	17.44	13.88	cLBV / FeII / B[e]SG	[1/6/3]	late-type companion
M33	J013350.12+304126.6	16.82	14.05	cLBV / FeII / B[e]SG	[7/6/3]	late-type companion
M33	J013410.93+303437.6	16.07	15.26	cLBV	[1]	cLBV

Table 1: Objects and proposed classifications from literature and ours. Magnitudes are from Simbad.

3. Observations

Medium-resolution ($R \sim 5900$) K-band spectra of our objects were obtained with the GNIRS spectrograph attached to the 8.1-m telescope at Gemini North. Data acquisition was between January 2019 and September 2020 with the short camera and the 111 l/mm grating centered on $2.3\,\mu$m for a wavelength coverage $2.2\,\mu$m $- 2.4\,\mu$m. The observations were carried out in AB pairs to facilitate sky subtraction. Data reduction was performed using standard IRAF tasks. Late B- or early A-type main-sequence stars were observed close in time and airmass for telluric correction.

4. Results

The spectra are shown in Figure 1. We detect emission from the hydrogen Pfund series in two objects, CO band emission from both isotopes (^{12}CO and ^{13}CO) in two objects, the two spectra with CO band absorption suggest late-type stars, while one spectrum appears to be featureless.

Object LGGS	$T_{\rm CO}$ [K]	$N_{\rm CO}$ [cm^{-2}]	^{12}CO/^{13}CO	$v_{\rm rot,los}$ [km s^{-1}]
J004320.97+414039.6	2200±1000	(3±1) × 10^{21}	3±1	60±10
J004621.08+421308.2	1500±1000	(5±1) × 10^{22}	50±10	60±10

Table 2: Best-fitting parameters of the CO band emission.

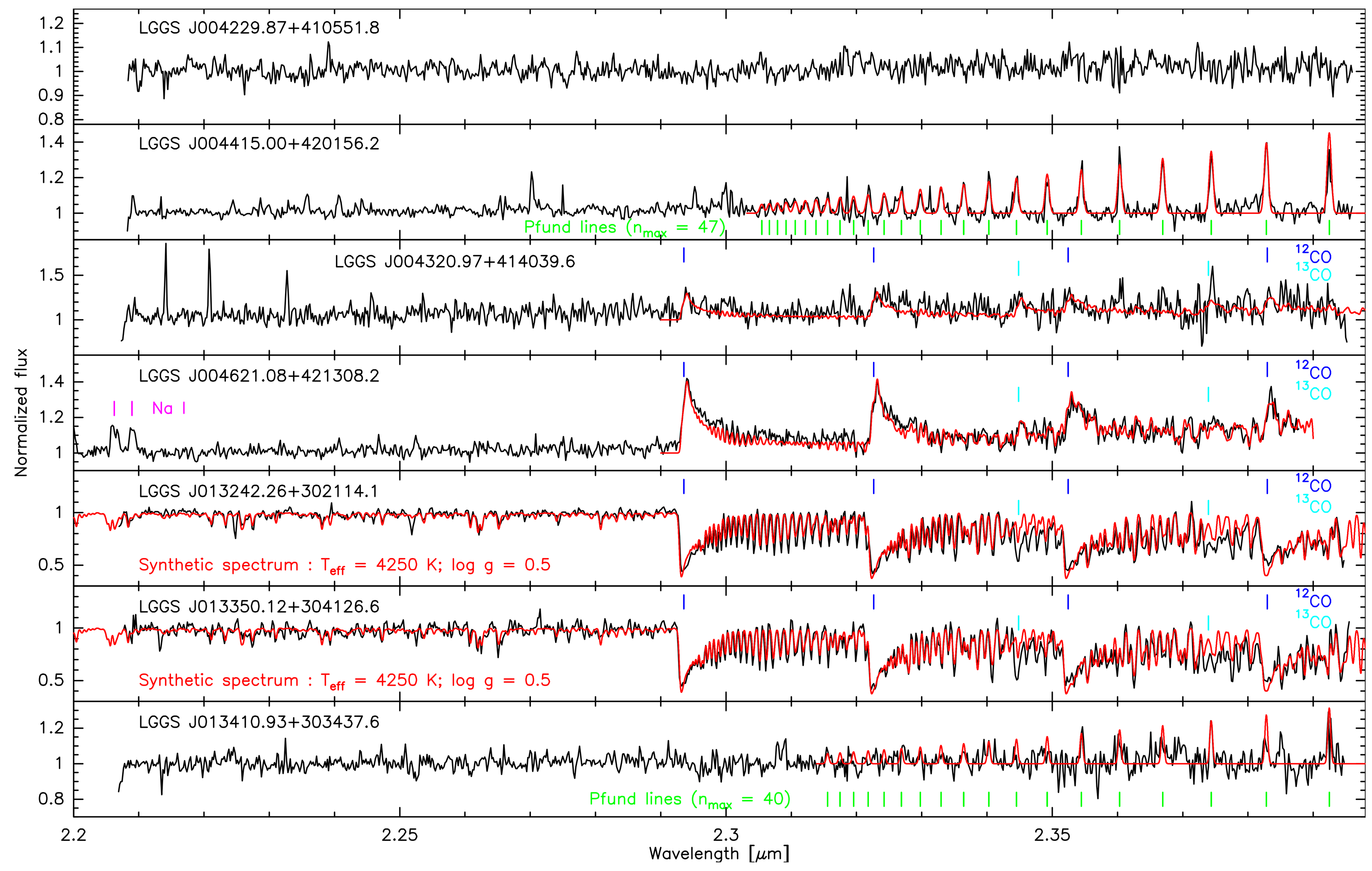

Figure 1: Best-fitting models (red) to the normalized GNIRS spectra (black) of our objects.

4.1 CO band emission

The shape of the band heads is characteristic of rotation, suggesting that the CO gas is most likely concentrated in a rotating circumstellar ring. We assume the CO gas is in LTE, which is justified by the high CO column densities typically observed, and compute the emerging spectra with our CO code [8,9]. The best-fitting parameters are listed in Table 2, and the fits are included in Figure 1.

4.2 Pfund line emission

The single-peaked profiles suggest that the lines form in the ionized wind rather than in a disk. The maximum detectable Pfund line, $n_{\rm max}$, is an indicator for the hydrogen density. We adopt Menzel's case B recombination, fix the electron temperature in the wind at $10\,000$ K, and assume that the lines are optically thin. The best-fitting parameters are listed in Table 3, and the fits are included in Figure 1.

Object LGGS	T_e [K]	$N_{\rm H}$ [cm^{-3}]	$n_{\rm max}$	$v_{\rm Gauss}$ [km s^{-1}]
J004415.00+420156.2	10^4	(1.9±0.3) × 10^{13}	47	60±10
J013410.93+303437.6	10^4	(4.9±0.7) × 10^{13}	40	60±10

Table 3: Best-fitting parameters for the emission of the Pfund series.

5. Discussion and Conclusions

J004229.87+410551.8 is located in a crowded region (cluster), likely contaminating the IR photometric measurements of this star. A B[e]SG classification of the object has already been questioned [10], and its featureless K-band spectrum resembles indeed more the LBV LHA 120-S 155 during outburst [12]. The K-band characteristics of **J004415.00+420156.2** and its high luminosity of $\log L/L_\odot = 5.73$ [2] align the star with high-luminosity B[e]SGs (LHA 120-S 22, LHA 120-S 127) in the LMC lacking CO band emission [10]. **J004320.97+414039.6** displays weak CO band emission. With its luminosity of $\log L/L_\odot = 5.01$ [2], it resides at the lower luminosity border of B[e]SGs showing CO band emission [10]. The intense CO band emission detected from **J004621.08+421308.2** is characteristic for B[e]SGs and occasionally seen in yellow hypergiants [13]. The recently determined stellar temperature of 12 000 K [11], shifts the star clearly to the B[e]SG domain. **J013242.26+302114.1** was recently excluded from the list of B[e]SGs due to its infrared colors that suggest it could have a late-type companion rather than circumstellar dust [10]. Our K-band spectrum confirms this. The intense CO absorption bands correspond to a late-type supergiant with $T_{\rm eff} < 4250$ K and $\log g \sim 1.0$ (included in Figure 1). Our observations suggest that **J013350.12+304126.6** also seems to have a late-type companion while it otherwise displays all characteristics of a B[e]SG. Whether circumstellar dust can still contribute to the total observed infrared excess of this object needs to be further investigated. The object **J013410.93+303437.6** is also known as Var 83 and has been classified by various studies as candidate LBV. With a luminosity of $\log L/L_\odot = 6.3$ [2] it is clearly more massive than all known B[e]SGs. The emission from the hydrogen Pfund series that we detected is rather weak but comparable to the one of the similarly luminous LBV star LHA 120-S 128 in the LMC [12].

To summarize, we have detected dense molecular gas rings around two B[e]SGs in M31 and a dense ionized wind from one M31 B[e]SG and one M33 cLBV. In addition, we discovered late-type companions in two M33 objects and that one LBV likely was in outburst at the time of our observations (2019-01-22). The presented data and analyses reinforce that near-infrared spectra are invaluable for identifying late-type companions and characterizing circumstellar environments, and they provide important complementary information that helps classifying evolved massive stars.

References

[1] Massey P. 2007, AJ, 134, 2474
[2] Humphreys R.M. et al. 2014, ApJ, 790, 48
[3] Humphreys R.M. et al. 2017, ApJ, 844, 40
[4] King N.L. et al. 1998, ApJ, 507, 210
[5] Gordon M.S. et al. 2016, ApJ, 825, 50
[6] Clark J.S et al. 2012, A&A, 541, A146
[7] Massey P. et al. 1996, ApJ, 469, 629
[8] Kraus M. et al. 2000, A&A, 362, 158
[9] Kraus M. 2009, A&A, 494, 253
[10] Kraus M. 2019, Galaxies, 7, 83
[11] Sarkisyan A. et al. 2020, MNRAS, 497, 687
[12] Oksala M. E. et al. 2013, A&A, 558, A17
[13] Kraus M. 2023, Galaxies, 11, 76

The observations were obtained under program IDs GN-2018B-Q-301, GN-2019B-Q-201, and GN-2020B-Q-230. This research has received funding from the project RVO:67985815, CONICET (PIP 1337), the Universidad Nacional de La Plata (Programa de Incentivos 11/G160), Argentina, and the European Union's Framework Programme for Research and Innovation Horizon 2020 (2014-2020) under the Marie Skłodowska-Curie Grant Agreement No. 823734.