Spectroscopic observations of emission-line objects at Bosscha Observatory

M Raffif Rabbani¹, Azlizan Adhyaqsa¹, Dimas A Prabowo¹, Aprilia¹, Lucky Puspitarini² and Hakim L Malasan²,³

¹Undergraduate Program in Astronomy, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
²Astronomy Research Division and Bosscha Observatory, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
³ITERA Astronomical Observatory, Jalan Terusan Ryacudu, Lampung 35365, Indonesia

Abstract. We report an optical spectroscopic observational program of emission-line objects at Bosscha Observatory. The observations were conducted on 18 nights between May to July 2019. We employ the spectrograph NEO-R1000 (R~1000) equipped with SBIG ST-8 XME CCD camera attached to a 28 cm (F/10) telescope and the spectrograph LHIRES III (R~5000) equipped with SBIG ST-402 CCD camera attached to a 25 cm (F/10) telescope. Data reduction has been carried out using longslit transform routines within the Image Reduction and Analysis Facility (IRAF). We have successfully obtained the spectra of 9 Wolf-Rayet (WR) stars, 13 B-emission (Be) stars, 2 Luminous Blue Variable (LBV) stars, 8 Herbig Ae/Be (H AeBe) stars, and 1 recurrent nova. The obtained spectra are presented and discussed in this paper.

1. Introduction
The study of spectroscopy provides us both the physical and chemical properties of the object of interest. The study of emission-line objects is particularly interesting because it offers the tools for understanding the physical state and dynamic structure of the envelopes and the active region of stars [1]. Optical spectroscopy of emission-line stars have been conducted since the 1970s at Bosscha Observatory. Among the objects observed spectroscopically are Be stars, WR stars, Herbig-Haro objects, planetary nebulae, and novae. The location of Bosscha Observatory which is near the Equator also provides a great prospect because objects on both the northern and the southern hemisphere can be observed evenly. The prospect of optical spectroscopy at Bosscha Observatory is further enhanced by the installation of the compact spectrograph NEO-R1000 [2]. The spectrograph was installed in 2015 as a realization of the memorandum of understanding between Institut Teknologi Bandung (ITB) and Kyoto Sangyou University (KSU). Currently, ITB and KSU are part of the nova observation network with the main focus on the spectroscopic observation of novae. Given the long history of optical spectroscopic observations that have been carried out at Bosscha Observatory [3], we continue the observation and extend the target of the types of emission-line objects. Our target objects include: novae, Be stars, WR stars, LBV stars, and H AeBe stars.
We report the optical spectroscopic observations of these emission-line objects that had been carried out at Bosscha Observatory between May to July 2019. The observations are carried out using two modes: low-resolution and intermediate-resolution mode. The low-resolution mode is aimed to identify the emission lines present in the objects, while the intermediate-resolution mode is aimed to see detailed features in the emission line and the line variation with time. We also present the low-resolution spectra of each observed stars and intermediate-resolution spectra specifically for Be stars.

2. Observation

The observations are carried out at Bosscha Observatory (S 6°49’, E 107°37’, 1310 MASL). The data presented in this paper were taken on 18 nights between May to September 2019. The target objects were selected from catalogs: WRCAT [4], GCVS [5], and Member of Herbig Ae/Be Stellar Group [6]. The target Be stars were taken from the list of annually-monitored Be stars at Bosscha Observatory. The alert of the observed recurrent nova V3890 Sgr was obtained from The Astronomer’s Telegram [7]. These types of emission-line objects are selected as targets because they are bright enough to be observed using our instruments so that an adequate signal-to-noise ratio (S/N) can be achieved without contaminating the spectra with the emission from city lights.

For low-resolution spectroscopy, we employed the spectrograph NEO-R1000 equipped with SBIG ST-8 XME CCD camera attached to SCT Celestron C-11 (11”, F/10). With a grating of 600 grooves/mm, this spectrograph provides a resolution of $R \sim 1000$. With such a resolution, we are able to see the overall features of the spectra in the optical region and identify the emission lines present. Fe-Ne-Ar lamp is employed as a comparison lamp to carry out wavelength calibration. We employed HR 7001 as a spectrophotometric standard star throughout the observation, to make flux calibrations. HR7001 has been observed at least twice at different altitudes for each observing night to deduce the extinction curve. The exposure time ranged from a few seconds to 900 s.

For intermediate-resolution spectroscopy, we employed Littrow High Resolution Spectrograph (LHIRES) III equipped with SBIG ST-402 ME CCD camera attached to SCT Meade 11” (F/10) telescope. LHIRES III is a commercial spectrograph manufactured by Shelyak Instruments [8]. For our purposes, the spectrograph was configured so that it is centered on Hα wavelength (~ 6563 Å). With a grating of 1200 grooves/mm, it provides a resolution of R~5000. Ne-Ar comparison lamp was used to carry out wavelength calibration. This setup is focused to observe Be stars because we need a detailed feature of one particular emission line to study the evolution of the circumstellar disk surrounding the star. We did not do flux calibration. Instead, the spectra were normalized to their continuum. The exposure time ranged from a few seconds to 3600 s.

Data reduction is carried out using Image Reduction and Facility (IRAF) (http://iraf.noao.edu). We carried out dark-subtraction and flat-fielding to produce clean images. For low-resolution data processing, we use longslit transform routines to obtain the spectra. During wavelength calibration, dispersion curves are fitted until we obtain an rms less than 0.1. Flux calibration is carried out with HR7001 as the spectrophotometric standard star. For intermediate-resolution data processing, we use apextract routines to obtain the 1-dimensional spectra. The resulting 1-dimensional spectra are then normalized to their continuum with a typical rms of 800. The spectra are then converted into text files to be reconstructed using the Python program. The identification of emission lines is carried out with the help of The Atlas of Emission-line Objects [9].

3. Results

In this section, we present the spectra of each object. The total numbers of objects observed are given in Table 1. All of the observed Be stars in the low-resolution mode are also observed in the intermediate-resolution mode, but we observed more Be stars in the intermediate-resolution mode because there was more time available to observe them on the observing nights as they are the only targets in this mode.
Table 1. Total observed objects with their subtypes.

| Type   | Subtype   | Low-resolution | Intermediate-resolution |
|--------|-----------|----------------|-------------------------|
| Be     | Single-peak | 5              | 6                       |
|        | Double-peak  | 3              | 4                       |
|        | Be-shell    | 3              | 3                       |
| WR     | WN         | 5              | -                       |
|        | WC         | 4              | -                       |
| LBV    | -          | 2              | -                       |
| HBe    | -          | 8              | -                       |
| Nova   | Recurrent  | 1              | -                       |

3.1. Be stars

We present one low-resolution and three intermediate-resolution spectra of 3 Be stars. The spectrum of a single-peak Be star HD148184 in both resolutions is presented in Figures 1a and 1b to give a sense of comparison. The spectra of double-peak Be star and Be-shell star are given in Figures 2a and 2b, respectively. Figure 1a shows that the emission lines are only present in the Hα and Hβ, while other Balmer lines show absorption. These observed properties are different from each target star. The intermediate-resolution spectra show details that cannot be observed in the low-resolution mode, such as the slight asymmetry of the line profile in Figure 1b, the double-peak in Figure 2a, and Be-shell profile in Figure 2b. The different emission profiles for each subtype are caused by the different orientation of the circumstellar disk surrounding the star relative to the observer [1].

![Figure 1a. Low-resolution spectrum of single-peak Be star HD148184.](image1)

![Figure 1b. Intermediate-resolution spectrum of single-peak Be star HD148184. The line profile shows slight asymmetry.](image2)

![Figure 2a. Intermediate-resolution spectrum of double-peak Be star HD157042.](image3)

![Figure 2b. Intermediate-resolution spectrum of Be-shell star HD158643.](image4)
3.2. WR stars
We present the low-resolution spectra of 2 WR stars. The WR stars observed are classified into WN and WC subtypes. In the WN subtype, the dominant lines are that of ionized nitrogen (N III, N IV, and N V) while the WC subtype shows dominant lines of ionized carbon (C III and C IV). The broad emission lines are attributed to the star’s high-velocity stellar wind [10]. The spectra of WN and WC stars are given in Figures 3a and 3b, respectively.

3.3. HAeBe stars
We present the low-resolution spectra of 2 HAeBe stars. In the optical regime, HAeBe spectra are characterized by continuum earlier than that of F0 and the presence of Balmer emission lines. Observation on the optical regime is not enough to identify HAeBe stars as they are pre-main sequence stars associated with dust envelope, and thus infrared observation is needed to observe the infrared excess [6]. The spectra exhibit several emission lines in the range 4000 - 4800 Å. The spectra are shown in Figures 4a and 4b.

3.4. LBV stars
We present the low-resolution spectrum of one LBV star. The spectrum is shown in Figure 5a, along with the zoom-in of the Hα line in Figure 5b. Due to the poor sky condition during observation, we did not carry out flux calibration for the spectrum. Instead, the spectrum is normalized to its continuum. The spectrum shows emission of H and He I lines. The spectrum also shows the P Cygni profile on the H I lines, indicating a mass outflow from the star. A higher resolution is needed to gain a better look of the line profile.
3.5. Nova

The nova observed was the recurrent nova V3890 Sgr which was first identified in 1990. The spectrum of V3890 Sgr shows broad emission lines of H I, He I, and He II. After its alert, the nova has been studied in multiwavelength observations, including optical [11], radio [12], infrared [13], and X-ray [14]. The observed spectrum is shown in Figure 6.

4. Concluding Remarks

The time-variability of emission-line objects will give us insight into the nature of the emission-line phenomenon observed in celestial objects. So, we will continue our observation to monitor nova alerts and the time variation of nova and other emission-line objects. From the obtained spectra, it is also possible to derive some astrophysical properties of the target objects including the expansion velocity of WR stars and the electron density of the nova.
Acknowledgments
We would like to thank Bosscha Observatory for providing us the types of equipment needed for this research. We would also like to thank P3MI for their support in this research.

References
[1] T Kogure and K C Leung 2007 The Astrophysics of Emission-Line Stars New York, Springer
[2] Malasan et al. 2016 Indonesian Journal of Physics 27 No. 1
[3] B Hidayat, K Ogura, M Shinohara 1995 IAU Colloq. 148: The Future Utilisation of Schmidt Telescopes 388 - 394
[4] K A van der Hucht 2001 New Astron. Rev. 45 135
[5] Samus et al. 2017 Astron. Rep. 61 80-88
[6] The P S et al. 1994 A&AS 104 315-339
[7] Strader et al. 2019 The Astronomer’s Telegram 13047
[8] Shelyak Instruments, https://www.shelyak.com/produit/lhires-iii/
[9] R Walker 2012 Spectroscopic Atlas for Amateur Astronomers (Cambridge University Press)
[10] C S Beals 1929 MNRAS 90 202-212
[11] H Maehara & K Isogai 2019 The Astronomer’s Telegram 13062
[12] Nyamai et al. 2019 The Astronomer’s Telegram 13089
[13] Rudy et al. 2019 The Astronomer’s Telegram 13059
[14] Orio et al. 2019 The Astronomer’s Telegram 13083