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NEO-R1000: A FAST AND EFFICIENT COMPACT SPECTROGRAPH FOR EMISSION LINE OBJECTS STUDY AT BOSSCHA OBSERVATORY

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Abstract

In 2015, the Institute Teknologi Bandung (ITB) signed a Memorandum of Understanding with Sangyou Kyoto University (KSU). One realization of collaboration between ITB and KSU is observational program of Novae using a compact spectrograph NEO-R1000 (Novae and Emission line Objects with Resolution of 1000). This spectrograph is mounted at the Celestron C-11 (*F*/10.0) reflector and supported by a Losmandy G-11 equatorial mounting inside the GAO-ITB sliding roof building, Bosscha observatory, Lembang. The unique configuration of this spectrograph is the employment of mirror collimator and camera lens with focal length ratio of 3:1. This makes it has high speed characteristics. A slit width of 6.5 μm (4.7" @ C-11 reflector) is combined with a fixed transmission grating of 600 grooves/mm and equipped with a ST-8 XME CCD camera (9 μm per pixel, 1530 × 1024 pixels), resulting in a resolution of $R \approx 1000$ at a wavelength of 5800 Å with effective spectrum wavelength coverage $\Delta\lambda$ 4000-8000 Å. NEO-R1000 spectrograph has additional peripherals such as a Fe-Ne-Ar hollow cathode tube (HTC) which is used as a comparison source. We take flat-field spectrum by using an acrylic board and a halogen lamp. The main primary aim of this spectrograph is to observe the Classical Novae in the southern sky as part of Collaborative Spectroscopic Observations for the Detection of Molecules in Classical Novae. This spectrograph can also be used to observe other emission line objects such as Planetary Nebulae, Comets, P Cygni star type, WR stars and Be stars. In June 2015, this spectrograph was successfully used to observe Nova Sgr 2015 no 2.
Further developments of this spectrograph includes constructing a rotator to be attached to the flange of telescope to ensure high flexibility in observation of extended objects. In the future, a fiber optic connecting output pupil with the entrance slit of the spectrograph will be deployed to improve observational effectivity while reducing the load of spectrograph on telescope.

Keywords: Spectrograph, astronomy, observation

INTRODUCTION

Current astronomical spectrographs for visually faint objects are usually carried out by using large diameter telescopes. However, astronomical events occurs at short to long span of time. These objects and events are more practical to be observed using small telescope owing to its needs and

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operations. Small telescopes are powerful arsenal for astronomical event observations prior to follow-up observations by larger telescopes.

Bosscha Observatory (longitude of 7h:10m:28s E, latitude of 6^o: 49': 30" S) is located 15 km in the north of Bandung city with altitude of 1310 m from above the sea level. Bosscha observatory has many spectrographs with various specifications and usabilities. Starting from the 71-cm Schmidt "Bima Sakti" reflecting telescope that uses sub-beam prism with low dispersion (315 Å/mm at Hγ line) [1], this configuration aims at survey of the southern sky. The GOTO spectrograph mounted at a 45-cm GOTO cassegrainian reflector has a grating of 900 grooves/mm, mirror collimator and fixed slit, producing spectra with low dispersion (93 Å/mm). Both of these spectrographs use photographic film as the detector. The era of CCD as detector in spectroscopic observation at Bosscha Observatory was begun from the BCS (Bosscha Compact Spectrograph) that uses a long slit with two types of grating (300 and 1200 grooves/mm), slit width of 80 μm, and gives low and medium resolutions (R~ 900-9000) [2]. There is also SBIG DSS-7 spectrograph that is used for portable telescopes, which has 5 different slit widths (50μm up to 200μm) and uses a diffraction grating, procuding low resolution (R~ 400) [3].

One realization of memorandum of understanding between Institut Teknologi Bandung (ITB) and the Kyoto Sangyou University (KSU) in 2015 is formation of collaborative spectroscopic observations for the detection of molecules in classical novae using a compact spectrograph NEO-R1000 (Novae and Emission line Objects with Resolution of 1000) [4]. This Spectrograph is mounted at Celestron C-11 (F/10.0) telescope and is supported by a Losmandy G-11 equatorial mounting, placed in GAO-ITB sliding roof building, Bosscha observatory. This spectrograph opens a new way to conduct observation of emission line objects and providing new facility of spectroscopic observation for astronomy students.

MODEL AND INSTRUMENT SPECIFICATION

Celestron C-11 Telescope

NEO-R1000 spectrograph is attached to the Celestron C-11 Schmidt-Cassegrain telescope with a diameter of 10 inches (279.4 mm, F/10) supported by a Losmandy G-11 equatorial mounting. Detailed technical specifications of this telescope can be seen in Table 1.

Table 1. Technical specifications of Celestron C-11 Telescope

Name	Celestron C-11
Optical Design	Schmidt-Cassegrain Reflector
Diameter aperture	10 inches (279.4 mm)
Focal length	100 inches (2794 mm) F/10
Plate Scale	13 μm/arc second
Secondary Mirror Obstruction	95.3 mm (34.1 % of main aperture)
Telescope throughput	0.9
Weight	± 12.3 kg

CCD camera

The detector that is used is the SBIG ST-8 XME CCD camera. An additional spectrograph-telescope interface was designed and built so that the light from the telescope can be received fully by spectrograph at the best focus. Technical specifications concerning CCD camera is shown in Table 2 [3].

Table 2. Specifications of CCD ST-8XME camera

Name	ST-8 XME CCD camera
Pixel size	9×9 μm^2
Pixel array	1530 × 1020 pixel
CCD Size	13.8 × 9.2 mm^2
Quantum efficiency	Up to 50% from 4300 Å to 8000 Å
Read noise	15 e^-/pixel
Dark noise	1 e^-/s/pixel
Weight	± 1 kg

NEO-R1000 spectrograph

In order to obtain emission line spectra from astronomical objects with low surface brightness (especially emission lines from planetary nebulae and novae) with an effective exposure time, the demagnification factor of this spectrograph, defined as f_{camera} / $f_{collimator}$, must be less than 1.0. Using this optical design, emission lines features from faint objects can be quickly and effectively detected.

The application of transmission grating and collimator mirror form compact configuration for this spectrograph. The emerged diffracted beam from grating requires CCD chip to be located as near as possible from the grating, and the chip size must be similar to or less than diffracted beam size. This spectrograph design is made to fit the telescope with focal ratio $F/8.0 \leq F/D \leq F/10.0$ and CCD with a chip size ≤ 14.5 mm.

Typical seeing size at Bosscha observatory is 2 arc seconds [2]. In order to optimize the observation under that seeing condition, NEO-R1000 slit width is configured to has fixed width of 65 μm that is proportional to 4.8 arc-second in projected sky at detector with a scale of 13.5 μm/arc-second.

NEO-R1000 uses a fixed 600 grooves/mm transmission grating with 15×15 mm^2. The technical specification of the spectrograph is given in Table 3.

Table 3. Technical specification of NEO-R1000 spectrograph

Type	Longslit and transmission type
Slit Width	65 μm
Slit height	7.5 mm
Slit position	Fixed
Collimator	Mirror system
Camera	Lens system
Collimator focal length	150 mm
F-ratio of collimator	*F*/10
Camera focal length	50 mm
F-ratio of camera	*F*/3.4
Grating	600 grooves/mm
Grating dimension	15 mm
Vignetting effect at the collimator	None
Diameter of beam exiting the collimator	15 mm
the spectral dispersion on the CCD	2.9 Å/pixel
Diameter of beam diffracted from grating	14.6 mm
Spectral range coverage	3547.5 – 7977.4 Å
Spectral resolution (R)	1000
Demagnification	1:3
Dimension of spectrograph	112 × 84 × 213.2 mm
Weight	10 kg
Comparison lamp	Hollow Cathode Tube (Fe-Ne-Ar lamp)

In Figure 1 we can see inner part of the spectrograph that contains a mirror to reflect the light from slit to collimator. The slit is combined with two mirrors separated by 65 μm so the light from the object is passed through the slit and the region around the object is reflected to slit viewer that is equipped with Watec TGV-M camera as a guider.

EXPERIMENTS WITH NEO-R1000 SPECTROGRAPH

Figure 2 displays the SBIG ST-8 XME CCD camera attached to NEO-R1000 spectrograph inside the GAO-ITB sliding roof building. The observation with NEO-R1000 spectrograph is set with spectrum dispersion along the horizontal direction of CCD pixel array (1530 pixels). The flat-field as calibration image is taken by putting acrylic board illuminated by a halogen lamp in front of the telescope as shown in Figure 3.

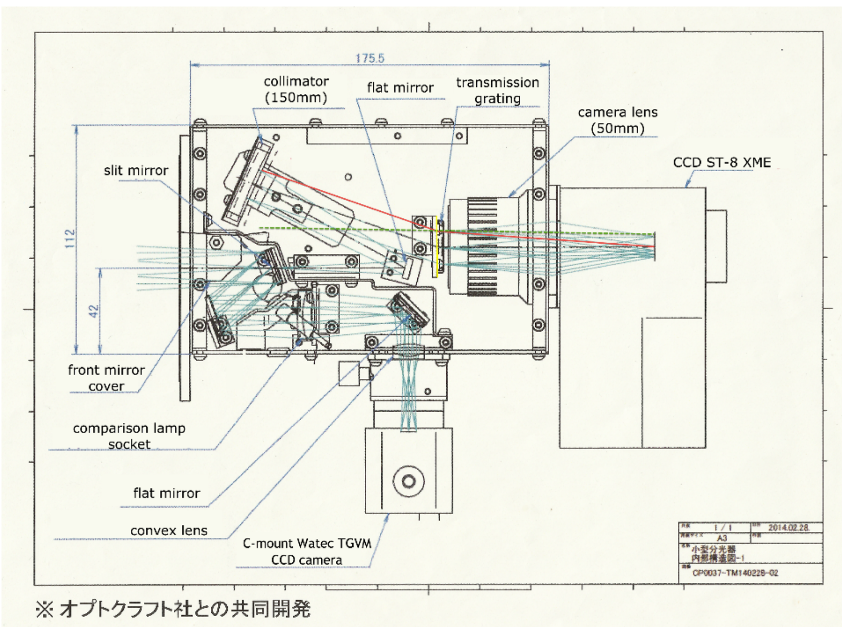


Fig. 1. The blueprint of NEO-R1000 spectrograph with SBIG ST-8 XME CCD camera (Source: Optcraft)

Fig. 2. SBIG ST-8 XME CCD camera and NEO-R1000 spectrograph attached to Celestron C-11 telescope.

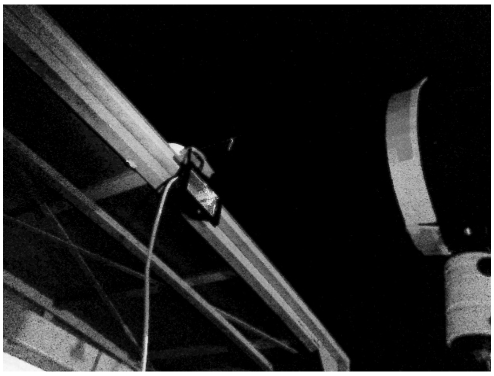
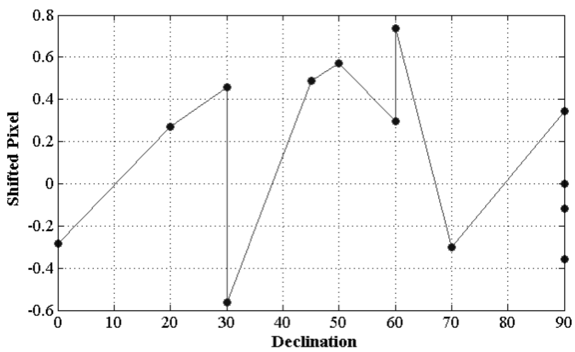


Fig. 3. The acrylic board and halogen lamp positions when taking flat-field image.

Instrument stability

Measurement of comparison lamp emission line position at various hour angles and declinations will provide us with information of the spectrograph-telescope stability. Celestron C-11 telescope, spectrograph NEO-R1000 and CCD ST-8 XME stability is shown in Figure 4. The amount of shift varies within hour angels and declinations. No systematic correlation are found. The maximum shift is about 1.3 pixels or about 3.7 Å. It is suggested that throughout the observations, two comparison spectra must be taken to bracket one object spectrum.



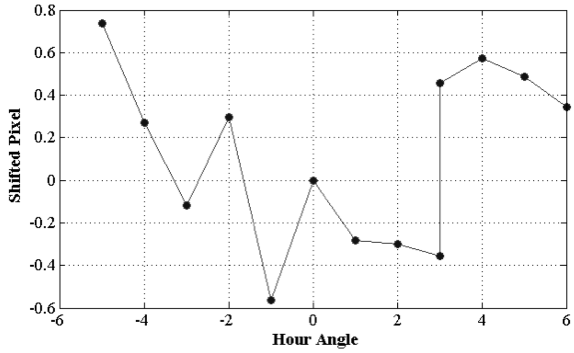


Fig. 4. Graph of emission line position shifts for different hour angle and declination.

Wavelength coverage

Optical components of spectrograph capable to produce spectral range from 3550 Å to 7950 Å, but in practice, the spectral response of detector has different range of sensitivity to capture the output spectrum from the spectrograph. The SBIG ST-8 XME CCD camera has sensitivity ranging from 4000 Å to 10000 Å [3]. Therefore, at the wavelength less than 4000 Å (~160 pixels from horizontal axis) degradation occurs due to lost of sensitivity of the detector. Astronomical observation with NEO-R1000 spectrograph and CCD ST-8 XME yield in the effective spectrum wavelengths coverage from 4000 Å to 7950 Å (see Figure 5).

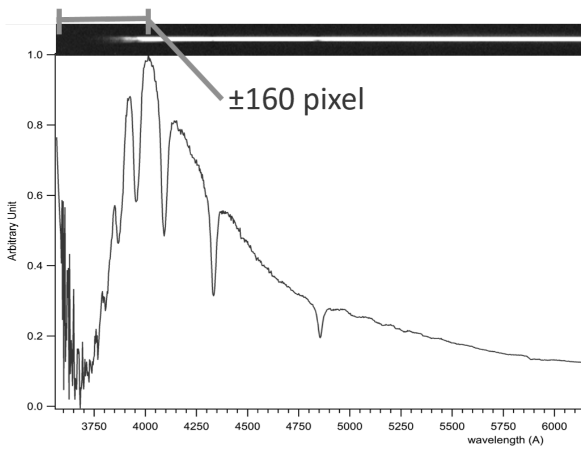


Fig. 5. Spectrum of Sirius coverning 3500 Å - 6000 Å taken with NEO-R1000 spectrograph.

Resolution

The spectrograph resolution measurement has been carried out by fitting Gaussian function to a single emission in the comparison source spectrum shown in Figure 6. Measurement of comparison source emission shows that at 5852.8 Å (Ne I), the full-width at half-maximum (FWHM) is 6.4 Å. The resolution for 5851.8 Å is deduced to be $R = \lambda/\Delta\lambda \approx$ 1000.

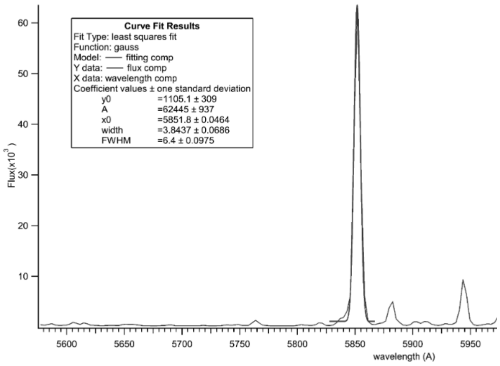


Fig. 6. Gaussian function fit to the Ne I emission at 5852.8 Å

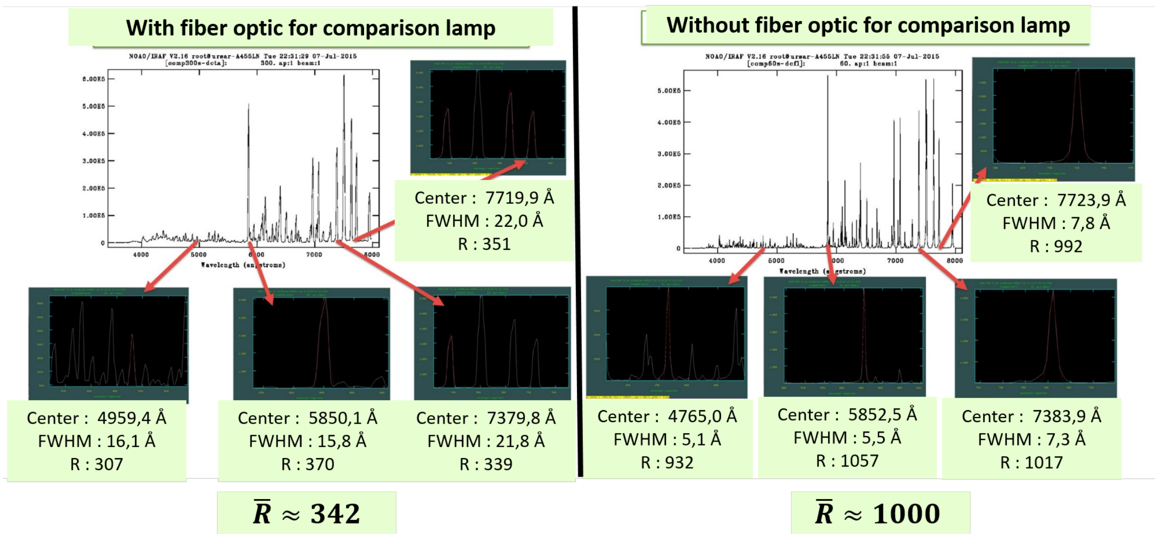


Fig. 7. Comparison of image and resolution values from two comparison lamp spectra with optical fiber (left) and without optical

The optical fiber influences to the comparison lamp spectra

An optical fiber has been employed in order to take comparison source spectra more easily and to maintain stability of the instrument during the observations. It is felt that the use of optical fiber degrades the spectral resolution. An experiment to the comparison source spectra's FWHMs with and without optical fiber (by putting the comparison lamp in front of the telescope), we found resolution value if using optical fiber was $R \approx 300$ while $R \approx 1000$ without optical fiber (See Figure 7).

THE ASTRONOMICAL PERFORMANCE

Signal-noise ratio (SNR) Model

Spectrograph system efficiency is influenced by atmosphere transmissivity, telescope, outcoming flux from spectrograph, and quantum efficiency of detector. This can be modeled to understand the entire spectrograph performance in producing astronomical spectra useful for measurements. For NEO-R1000 spectrograph with resolution about 1000, the SNR can be calculated, leading to the limiting magnitude of the observed spectra with typical SNR [5].

In Figure 8 theoretical SNR models as function of star magnitude and integration time is shown.

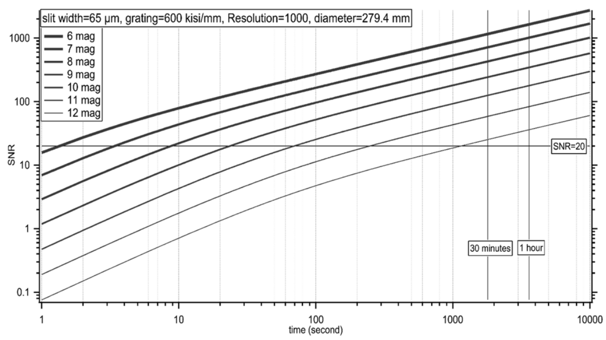


Fig. 8. SNR curve as function of stellar magnitude and integration time.

From the figure it can be seend that NEO-R1000 spectrograph system is able to produce SNR above 20 for magnitude 12 with integration time up to 1000 seconds.

The observation of Nova Sgr 2015 no. 2

The observation of Nova Sgr 2015 no. 2 has been carried out at 12 June, 23 June and 15 August 2015 [6]. Optical spectra of Nova Sgr 2015 was obtained and its variation has been monitored. The typical emission lines of nova and its variation were successfully detected from this observation. The P-Cygni profile which shows the hot shells formation that expand quickly after nova explosion (see Figure 9) clearly appeared in the observation of 12 June and 23 June.

The Observation of point sources and extended sources

In addition to nova observation, NEO-R1000 was successfully used to observe several bright stars in the Orion constellation (see Figure 10) and emission-line objects such as P-Cygni star, Be star, Wolf-Rayet star and nebula (see Figure 11).

In the future, this spectrograph will be used in research of astronomical object classification, spectral variability monitoring, outburst detection and measurement of velocities related to star explosion. To support these researches, NEO R-1000 spectrographs will be enriched with some additional peripherals such as:

1. a spectrograph rotator, to support configuration flexibility in typical observation of extended object such as comet and planetary nebulae.
2. an optical fiber which connecting the telescope to NEO-R1000 spectrograph in order to keep the stability of the instruments and to overcome excessive load on the telescope.

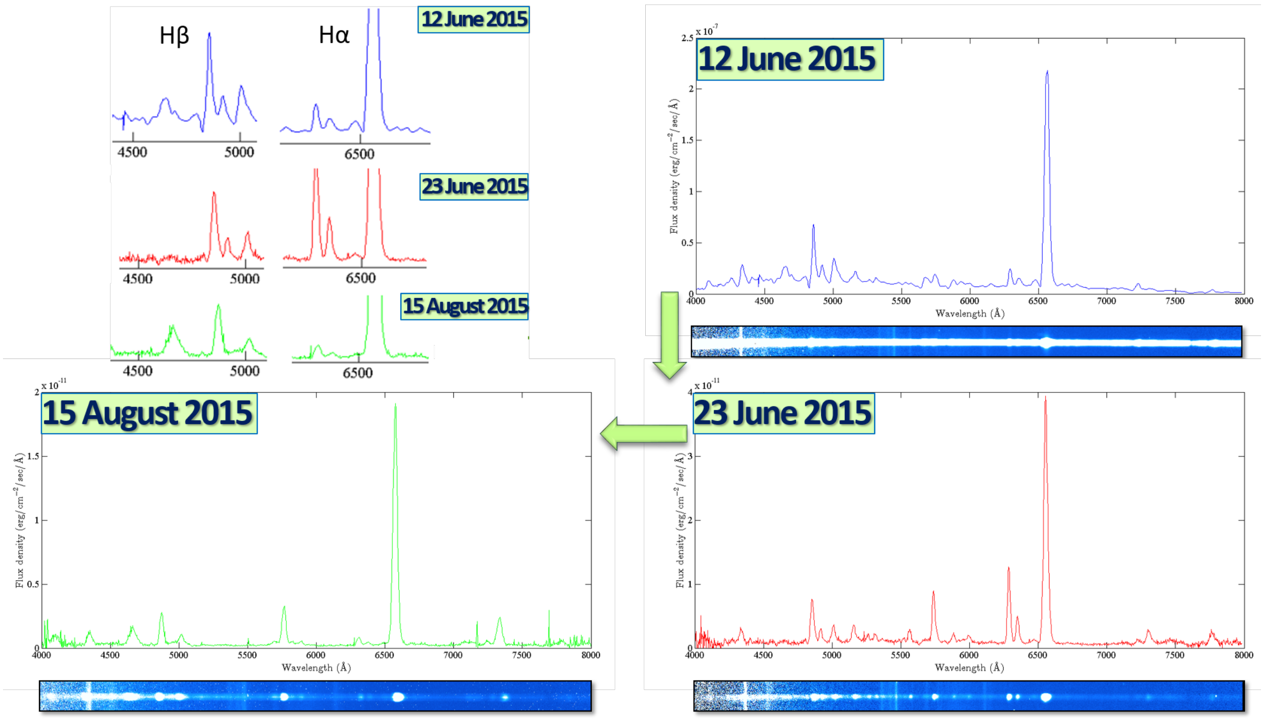


Fig. 9. The spectra and spectrograms of Nova Sgr 2015 no 2 at 12 June, 23 June and 15 August 2015.

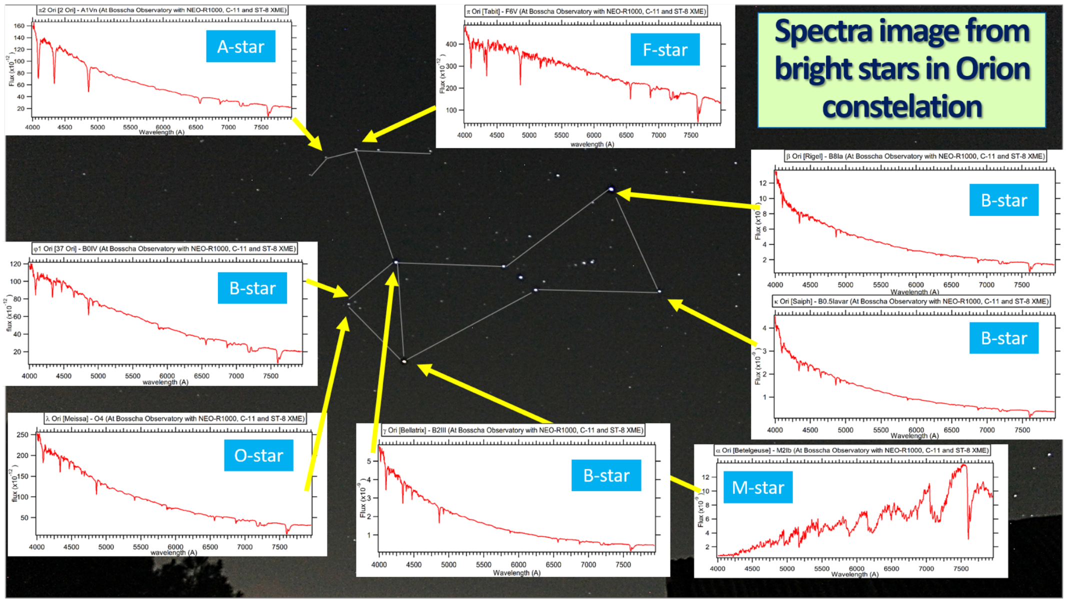


Fig. 10. spectra image from bright stars in Orion constellation.

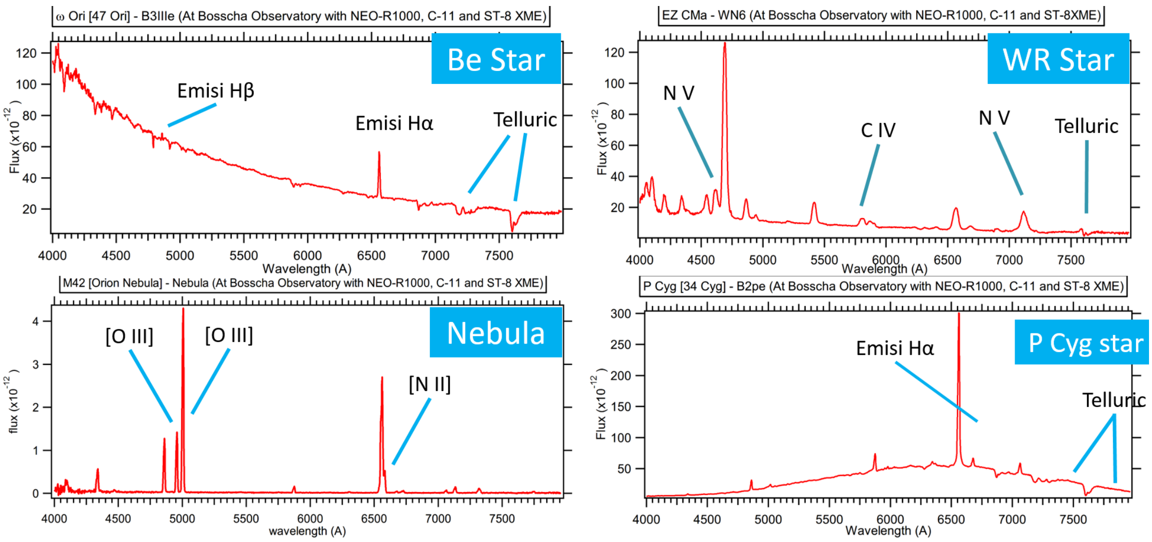


Fig. 11. The spectra image from Be-star, Wolf-Rayet star, P-Cygni star and Orion nebula.

CONCLUSIONS

From the instrument experiment and astronomical performance study with C-11 telescope, NEO-R1000 spectrograph and SBIG ST-8 XME CCD camera, it can be concluded that

1. Instrument stability is about 1.3 pixels or 3.7 Å,
2. Effective wavelength coverage of the entire system is 4000A - 7950Å,
3. Empirical resolution of NEO-R1000 spectrograph (without fiber optic) is R $=\lambda/\Delta\lambda \approx 1000$, optimum for velocity measurement and classification
4. The spectrograph is complemented with optical fiber for the comparison lamp, however it can degrade the spectra resolution,
5. Limiting magnitude for SNR= 20 (with integration time= 1000 seconds) is 12 magnitude,
6. NEO-R1000 spectrograph is effective for observation of point sources and extended sources and this spectrograph was successfully used to observe Nova Sgr 2015 No. 2.

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