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THE NIGHT SKY SPECTRUM OF MOUNT BOHYUN

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ABSTRACT

Spectrophotometry of the night sky over Mount Bohyun is presented for the nearly entire visible wavelengths of 3600 ~ 8600Å. The data was obtained under moonless clear sky in February 2004 with the 1.8-m telescope and the long slit spectrograph. The sky spectrum shows a number of strong emission lines originated from light pollution, especially due to high pressure sodium lamps. When compared to the night sky of Kitt Peak, our sky continuum is 1 to 2 magnitude brighter at all wavelengths, the worst being around the broad emission region near 6000Å. The night sky spectrum presented here with almost complete line identifications is a useful reference for arc-independent wavelength calibrations to check the gravity flexure of the spectrograph and the wavelength shift between FeNeArHe arc frames and science frames.

Key words : atmospheric effects — techniques: spectroscopic — line: identifications

I. INTRODUCTION

Bohyunsan Optical Astronomy Observatory (BOAO) is located on top of Mount Bohyun and is the place for major observational facilities for Korean optical astronomy. Mount Bohyun is one of dark locations in Korea, but only relatively so. It has been suspected that the sky would suffer from the artificial light of several well populated cities within the distance of 50km, but detailed characterization of its night sky has not been made until now.

Using the new Long Slit Spectrograph (LSS) of BOAO (Kim et al. 2003) and the 1.8-m reflector, we obtained the spectrum of night sky in the absence of the Moon. Our spectrum covers the entire visible wavelengths of 3600 ~ 8600Å, which are filled with numerous sky emission lines of both artificial and natural causes. We present here our spectrum in the form of absolute spectrophotometry, so that it can be compared with the night sky of other observatories as well as with future measurements on Mount Bohyun. The brightness and spectral character of the night sky is one of the fundamental qualities of an observing site. Therefore in order to maintain good understanding on the sky conditions and their temporal variations, it is necessary to carry out spectroscopic study over long period of time (see for example, Massey and Foltz 2000 and Osterbrock and Martel 1992).

In contrast to the damaging effect to most astronomical observations, however, the night sky emission lines can be a useful tool for spectroscopy. There are many strong sky lines of known wavelengths, which are good natural wavelength calibrators. Considering the fact that the BOAO spectrograph still suffer from spectrogram shifts related to gravity directional variations (Kim et al. 2003), it is not always reliable to calibrate the wavelengths based on the Arc exposures alone. This is especially the case if one makes a very long exposure and/or if the arc exposures are not taken soon enough. The comparison of sky line locations with predicted wavelengths can be more reliable and readily usable choice of calibration.

II. OBSERVATIONS

The sky spectrum was obtained in the course of our test run with the LSS on the night of February 27, 2004. Our intention was to see if the throughput of the 1.8-m system together with LSS is good enough for the observations of very faint QSO candidates. This test was made during a brief break between our main program observations with the Echelle spectrograph, but still provides us with a useful spectrum for the present work.

We used the 150 groove/mm grating. With the 1K CCD installed for the LSS, the usable wavelength coverage is from 3600Å to 8600Å with a pixel dispersion of 5.2Å/pixel. The spatial plate scale is 0.72″/pixel. We chose the slit width of 300μm, which corresponds to 4.3″. The spectrograph system is equipped with two tungsten halogen lamps for flatfielding and the FeNeArHe lamp for wavelength calibration. Detailed descriptions of the mechanical structure and instrument parameters are given in Kim et al. (2002).

We observed a 16.3 V-magnitude object with a 600-second exposure at the zenith distance of approximately 30 degree. The continuum of this object is barely detected at the level expected from its V-magnitude, and did not show strong emission signature of QSO. The sky information in the present paper is extracted from this single frame. Two flux standard stars,

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HD93521 and Feige56, were also observed. The seeing was approximately 2″. Five arc calibration frames were obtained for wavelength calibration.

The data frames are processed with IRAF. The preprocess is done for bias and flatfield but not for dark subtraction. Our dark exposure of 3600 seconds, taken at the end of the night, proves that the dark current is negligible ($\sim$ 2 counts/hour). Fig. 1 shows our long exposure image after the preprocessing. The horizontal bright line in the middle corresponds to the 16.3 V-magnitude star while many vertical lines are the night sky emission features. 1-D spectrum is extracted by collapsing the pixels perpendicular to the dispersion axis, for which we used a FORTRAN program based on the CFITSIO library. For standard stars, the extraction is made for the 22 rows ($\sim$ 16″) with stellar line in the middle. For the sky spectra, we collapse the same area but away from the stellar line. We could have used much wider area for the night sky for somewhat better S/N ratio, but this would have required a two-dimensional wavelength calibration; our data exhibit slight wavelength shift in the spatial direction. We adopt simpler one-dimensional wavelength calibration, which is thought to be adequate for the purpose of present work.

For flux calibration, we used following references; Oke (1990)'s 1Å and 2Å binned data for HD93521 and Hamuy et al.(1994)'s 50Å binned data for Feige56. Because we did not have the atmospheric extinction curve for Mount Bohyun, we adopted the KPNO atmospheric extinction in IRAF database. These stars provide two independent response functions, which turned out to be nearly identical. The quality of our flux calibration can be shown by applying the response function from HD93521 to each of the standard star spectra and compare them with the original reference data. Fig. 2 shows the comparison made in AB magnitude system (Oke 1974); the calibration appears quite appropriate for both stars at all wavelengths. The only notable differences are in the regions of strong sky absorption, the O_2 A-band at 7594Å and the O_2 B-band at 6867Å. These absorption features need to be considered if we were to calibrate spectra of other stars or galaxies, but it is irrelevant for the present study of sky emission characteristics.

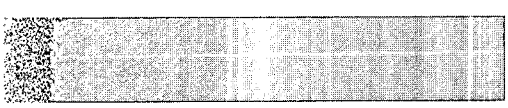

Fig. 1.— Preprocessed image showing the spectrum of a 16.3 V-magnitude star and numerous night sky emission lines. The stellar continuum is very weak and dominated by the sky.

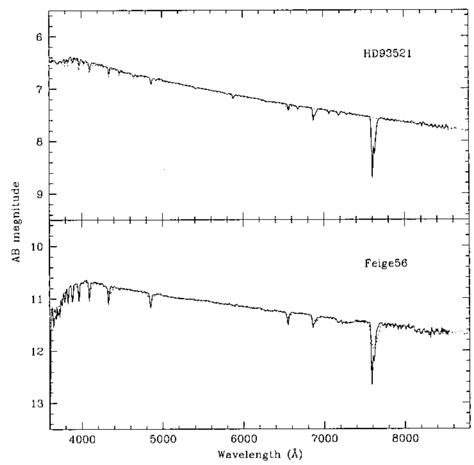

Fig. 2.— Flux calibrated spectra (*solid lines*) of standard stars HD93521 and Feige56 superposed onto the literature values (*broken lines*).

III. SKY SPECTRUM

The fully calibrated night sky spectrum is given in Fig. 3. No attempt has been made to correct for the airmass, therefore this is still for the zenith distance of 30 degrees. In the same figure, we also plot the sky spectrum at the zenith of Kitt Peak given by Massey and Foltz (2000). The latter spectrum was obtained with the 0.9-m telescope and GoldCam CCD spectrometer with a spectral resolution of 10Å (FWHM). Even considering the difference in zenith distance, it is clear from the figure that the sky over Mount Bohyun is much brighter than Kitt Peak at all wavelengths. Our sky brightness reaches 19 AB mag/arcsec^2 at around 5900Å and become darker to 21 AB mag/arcsec^2 toward shorter wavelengths of around 5200Å and to 20.5 AB mag/arcsec^2 toward longer wavelengths of around 6600Å. In short wavelengths, the sky become bright again below 4000Å.

The strong broad peak centered on 5893Å with a wing span of over 1000Å is mostly due to Na D line that comes from high pressure sodium (HPS) lamps. HPS lamps are presently most popular lights in city areas. At the line center, there is a dip caused by self-absorption. The Kitt Peak data shows a narrow emission line in the same place; this narrow line comes from low pressure sodium (LPS) lamp demonstrating the benefit of LPS for astronomical night sky.

The blueward brightening below 4000Å is absent in the Kitt Peak data, but the spectrum of Osterbrock and Martel (1992), taken for the light polluted sky over Lick Observatory, show similar brightening. We are however still reluctant to draw a firm conclusion here because this might be due to the fact that LSS has very low sensitivity in this region. Therefore a small offset

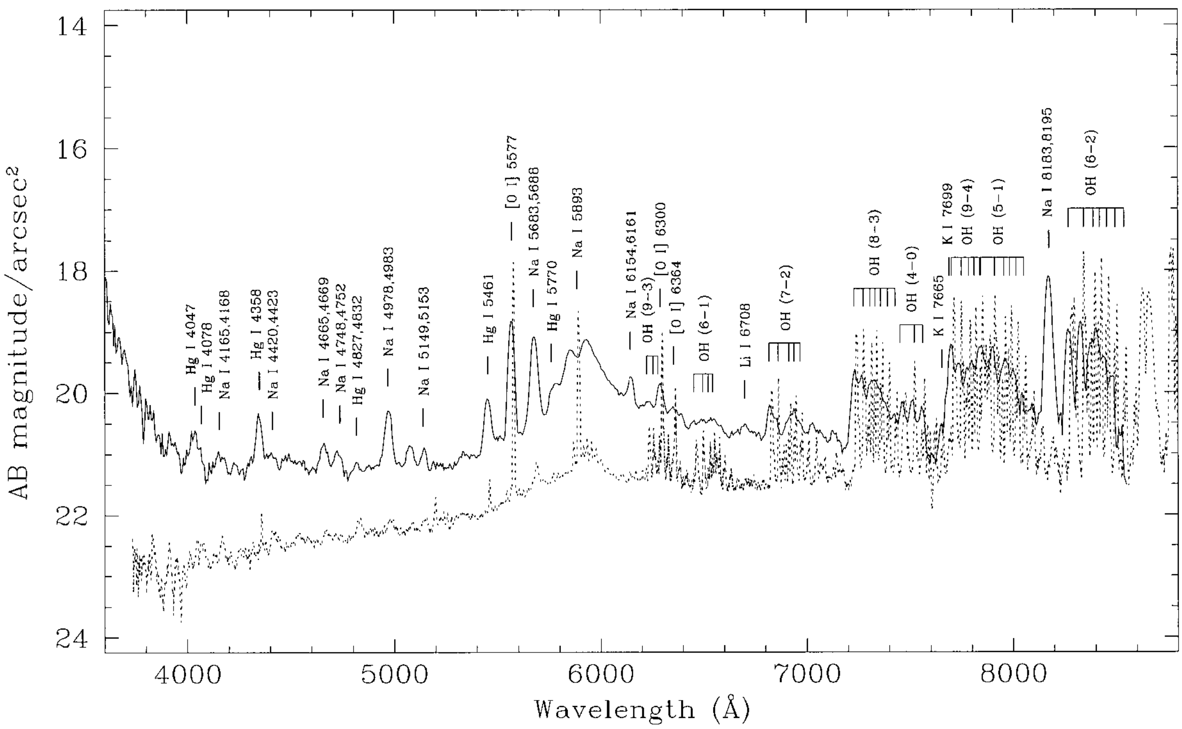

Fig. 3.— Night sky spectrum over Mount Bohyun (*solid line*) compared with Kitt Peak (*broken line*) of Massey and Foltz (2000).

in flux calibration can cause large systematic error in short wavelength. We also note that the present brightness distribution is affected by the use of KPNO atmospheric extinction curve in our flux calibration process. If the extinction over Mount Bohyun is far different from KPNO, the sky brightness level and also its wavelength dependence would change accordingly.

Line identification is made by combining the information given in Massey and Foltz (2000) and Osterbrock and Martel (1992). The strongest lines in our night sky come from HPS, i.e. Na I emissions. Besides the very broad feature centered at 5893Å, strong lines are also seen at around 4980, 5685, and 6157Å. The strongest of Na I lines, at 8190Å, however originates from LPS. This line is somehow completely absent in Kitt Peak data. Another popular city lights, mercury-vapor lamps and their Hg emission lines, do not seem to cause as much trouble as HPS. The Li I line at 6708Å and K I lines at 7665, 7699Å are from the impurity of sodium lamps.

Among the strong lines, the natural sky emissions are [O I] lines at 5577, 6300 and 6364Å and OH molecule lines. The latter contributes greatly to the night sky of wavelengths longer than 6600Å.

There is one emission line at around 5080Å for which solid identification could not be made. This line is not seen in the Kitt Peak spectrum. The spectrum of Osterbrock and Martel (1992) does contain this line but without any identification. Spectrum of Toronto sky (http://www.astro.utoronto.ca/DDO/prospective/torontosky.html) also shows this line clearly, but again without identification. An old study of Toronto sky by Lane and Garrison (1978) has a remark that multivapor lamps produce an emission at 5073.08Å, and this is the closest line identification we could find for this emission feature.

IV. SUMMARY

To our knowledge, this is the first spectroscopic study on the night sky of an observing site in Korea. Being close to cities that have a potential for large growth, BOAO always faces the danger of deteriorating sky conditions. In order to maintain scientific competitiveness, it is important to maintain our awareness of the night sky characteristics. The study of night sky spectrum presented here can be easily done with data obtained for other scientific purposes. Repeated measurements in the future will be necessary for the long term monitoring of night sky over Mount Bohyun.

We emphasize that the night sky emission lines offer a good wavelength calibration reference frame. Because they are obtained simultaneously with program target spectra, there cannot be any discrepancy caused by gravity directions and other instrumental effects. The sky lines are also very strong and easily recognizable. An independent wavelength calibration with these sky lines offer valuable opportunities to test the validity of FeNeArHe-based calibrations and also to study in detail the degree of wavelength shift caused by instrument flexure or telescope/rotator setup.

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