



The Night Sky Spectrum of Xinglong Observatory: Changes from 2004 to 2015

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Abstract

We present spectroscopic measurements on the night sky of Xinglong Observatory for a period of 12 years from 2004 to 2015. The spectra were obtained on moonless clear nights using the OMR spectrograph mounted on a 2.16-m reflector with a wavelength coverage of 4000–7000 Å. The night sky spectrum shows the presence of emission lines from Hg I and Na I due to local artificial sources, along with the atmospheric emission lines, i.e., O I and OH molecules, indicating the existence of light pollution. We have monitored the night sky brightness during the whole night and found some decrement in the sky brightness with time, but the change is not significant. Also, we monitored the light pollution level in different azimuthal directions and found that the influence of light pollution from the direction of Beijing is stronger compared with that from the direction of Tangshan and other areas. An analysis of night sky spectra for the entire data set suggested that the zenith sky brightness of Xinglong Observatory has brightened by about 0.5 mag arcsec⁻² in the *V* and *B* bands from 2004 to 2015. We recommend consecutive spectroscopic measurements of the night sky brightness at Xinglong Observatory in the future, not only for monitoring but also for scientific reference.

Key words: light pollution – instrumentation: spectrographs – methods: data analysis – site testing

Online material: color figures

1. Introduction

The Xinglong Observatory of the National Astronomical Observatories, Chinese Academy of Sciences (NAOC), is one of the major optical observatories in China, located at a distance of 120 km northeast from Beijing, China. The observatory hosts nine optical telescopes with apertures ranging from 0.5 to 4 m in diameter. There are about 63% spectroscopic nights per year to perform observations from this site (See Zhang et al. 2015).

Night sky brightness is one of the fundamental parameters of an optical observatory that restricts the limiting magnitude for any planned observations. The brightnesses of a moonless night sky are generated from natural sources, mainly contributed by airglow, zodiacal light, and integrated starlight (Leinert et al. 1998), and from artificial sources due to the lighting systems of neighboring towns (Della Prugna 1999). With the economic development and population growth of the surrounding cities, their attendant light pollution also grows. Jiang et al. (1999) presented an identification of the night sky emission lines of Xinglong Observatory with spectral coverage from 5300 to 8200 Å during 1996–1998 and found that Na I and Hg I lines from artificial sources are quite weak.

Previous studies on sky brightness have mainly measured sky brightness using broadband photometry. However, such measurements sometimes may be misleading, as they encompass both natural airglow and artificial sources (Massey & Foltz 2000). In order to better understand the contribution of atmospheric and artificial light sources, spectrophotometric measurements on sky brightness have been suggested, because they can clearly distinguish the artificial sources from the natural sources. Neugent & Massey (2010) presented a way to identify the contribution from the specific elements that influence overall sky brightness.

Spectrophotometric measurements have been widely used at various international optical observatories. Della Prugna (1999) presented a survey in Venezuela and Italy using a small spectrograph with spectral coverage from 4100 to 6400 Å. Night sky spectra of the Kitt Peak during 1988 were analyzed with wavelength coverage from 3800 to 6500 Å by Massey et al. (1990). Then Massey & Foltz (2000) presented an absolute spectrophotometry of the night sky from ~3700 to 6700 Å over two astronomical sites in southern Arizona, Kitt Peak, and Mount Hopkins, and measured for different azimuthal directions and different zenith distances, then

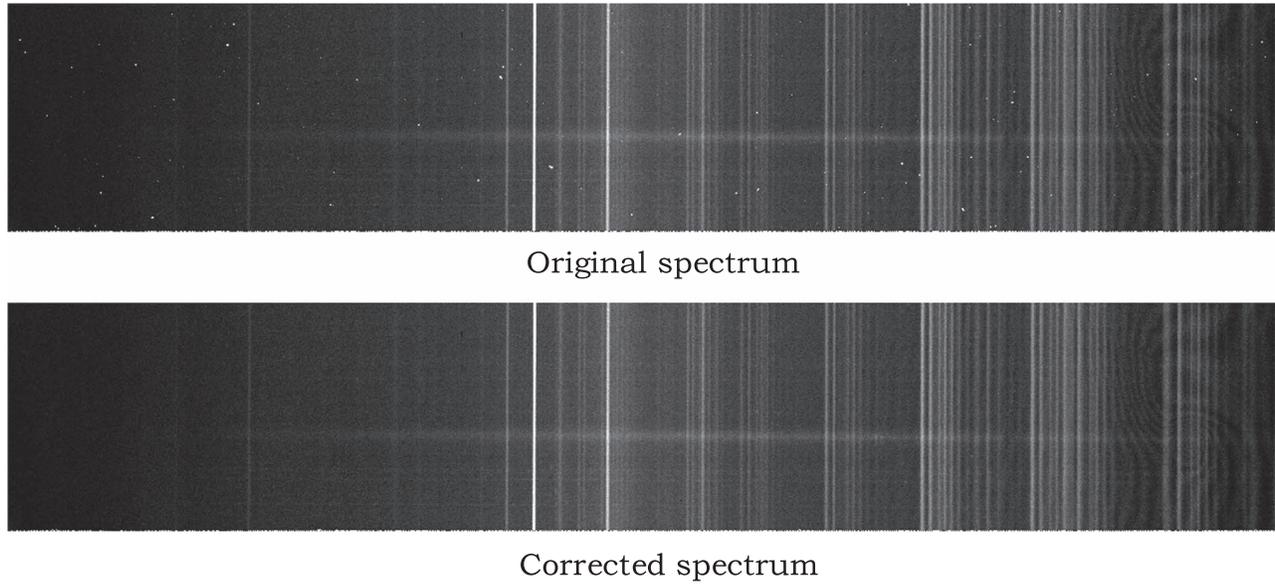


Figure 1. Comparison of a sample 2D spectrum before (upper panel) and after (lower panel) cosmic-ray removal.

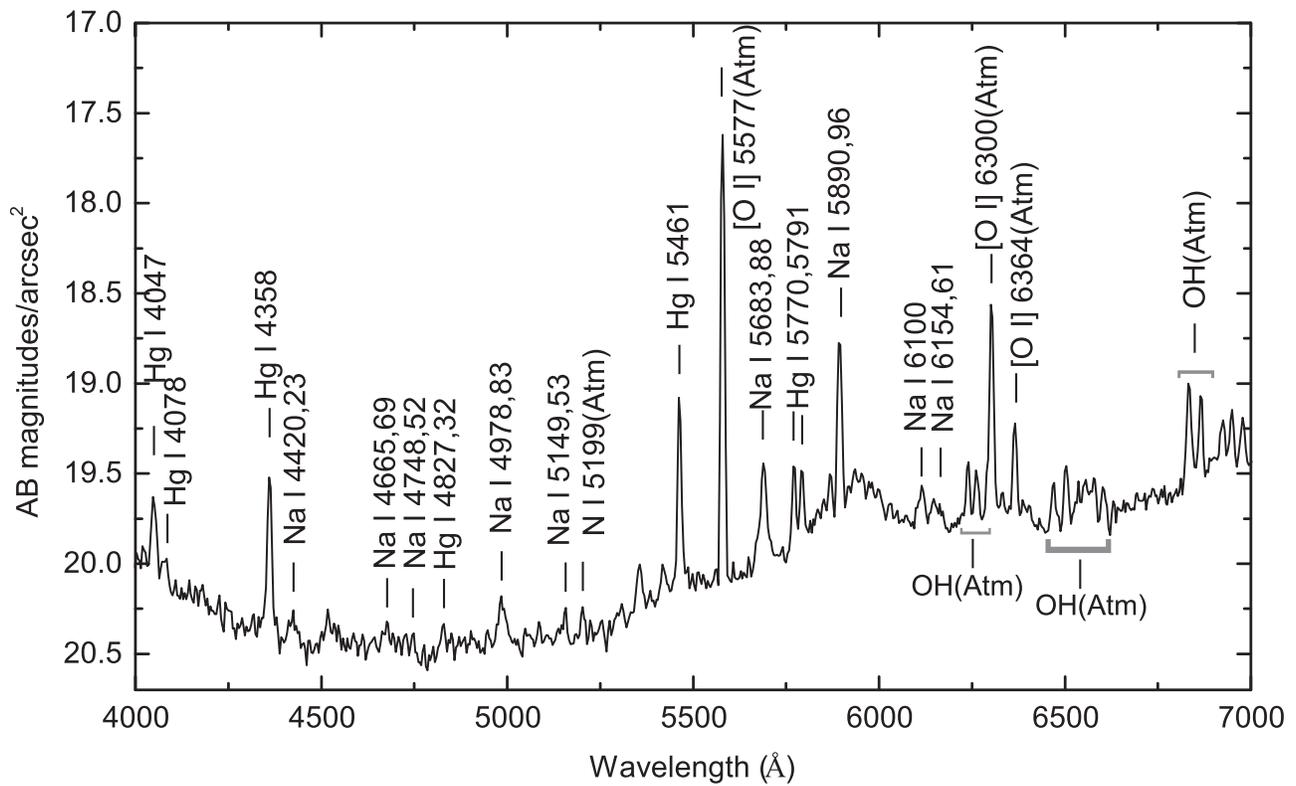


Figure 2. A typical spectrum in the range of 4000 to 7000 Å of the night sky at Xinglong Observatory. Emission lines from natural (atmosphere) and artificial (Hg and Na) sources are identified and marked.

converted to broadband magnitudes and gave a comparison with the night sky spectra in 1988. Neugent & Massey (2010) presented new absolute spectrophotometry of the Kitt Peak night sky during 2009–2010, and they strove to use the same

observation and data reduction manner of Massey & Foltz (2000), and compared that with published data. Sheen & Byun (2004) presented the spectrophotometry of the night sky from the Bohyunsan Optical Astronomy Observatory (BOAO),

which is located on top of Mount Bohyun, with nearly the entire visible wavelength from 3600 to 8600 Å, and the authors compared the night sky spectrum with that of Kitt Peak. Site testing for observatories also used the night sky spectra to analyze local light pollution (e.g., Sánchez et al. 2007; Moles et al. 2010). These night sky studies are mainly based on relative low-resolution spectra, but there may be different spectral coverage and blended lines. In order to identify as many lines as possible from the contribution of light pollution, Slanger et al. (2003) presented the night sky spectrum of light pollution at the Lick Observatory from 3800 to 9200 Å, with a high spectral resolution ($R \sim 45000$), and identified a large variety of lines from light pollution.

In this work, we study the night sky brightness for a period of 12 years using the spectroscopic measurements in visible wavelength. This paper consists of four sections. Section 1 gives a brief introduction of Xinglong Observatory and the research basis of night sky spectra around the world. Section 2 describes the details of our data acquisition and reduction. Analysis of the night sky spectrum at Xinglong Observatory and its results are presented in Section 3. We discuss our results and present our conclusions in Section 4.

2. Data Acquisition and Reduction

The spectral data used in our study were from observations of the 2.16-m reflector at Xinglong Observatory. The telescope is equipped with three instruments; (1) the Beijing Faint Object Spectrograph and Camera (BFOSC) available for imaging and low-resolution spectroscopy; (2) the spectrograph made by Optomechanics Research Inc.(OMR) for low-resolution spectroscopy; and (3) the Fiber-fed High Resolution Spectrograph (HRS). A detailed introduction and an up-to-date status report for these three instruments will be provided in Fan et al. (2016, in preparation). We searched the raw data from the OMR and BFOSC archives for our analysis. Because our study is by-product of the research interests of various observers who obtained data with different instruments, we need to select the appropriate data depending on our requirements, using the log files of the 2.16-m telescope recorded by astronomers on every observing night. This selection procedure is an essential yet complicated element of this study. The main criteria for selecting the low-resolution spectroscopic data are as follows: (1) moonless clear nights with good astronomical seeing; (2) exposure times should be at least 1800 seconds, and 3600 seconds is ideal; and (3) the preferable location for objects is at least 15° away from the galactic plane, as suggested by Massey & Foltz (2000). We ensure that all the selected data were observed with the same spectrograph set-up, leading to an accurate comparison. Finally, we decide to select the OMR data for our night sky

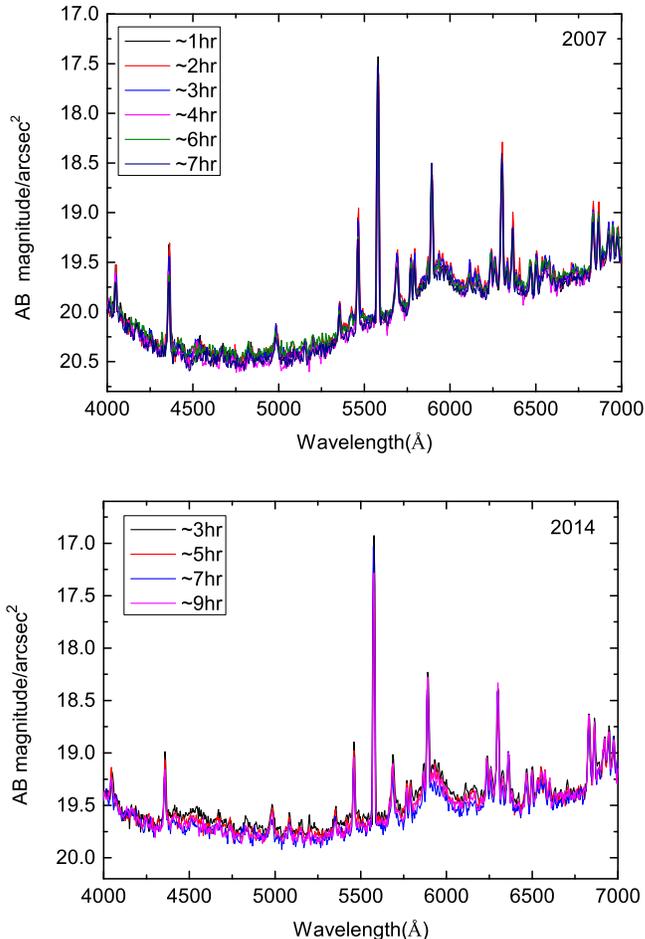


Figure 3. The variations in night sky brightness with time during 2007 and 2014 are shown.

(A color version of this figure is available in the online journal.)

spectrum analysis by considering the resolution, wide wavelength coverage, and long time span.

OMR spectra are taken on a Princeton Instruments (PI) PIXIS 1340×400 CCD with a pixel size of $20 \mu\text{m}$, and a pixel scale of $0''.96$. We selected the spectral data taken with the $3001/\text{mm}$ grating, which provides a dispersion of $4.0 \text{ \AA}/\text{pixel}$ that covers the required wavelength coverage of $4000\text{--}7000 \text{ \AA}$. As the mean and median seeing value of Xinglong Observatory over an year are $1''.9$ and $1''.7$, respectively (see Zhang et al. 2015), we selected a slit width around $2''.3$ in order to include more photons and improve the signal-to-noise ratio (S/N). There are different lamps for OMR wavelength calibration and flat-field correction; here we used the He-Ar lamp for our spectral wavelength calibration and the halogen tungsten lamp for flat-field correction. Every night more than two spectroscopic standard stars were observed for flux calibration.

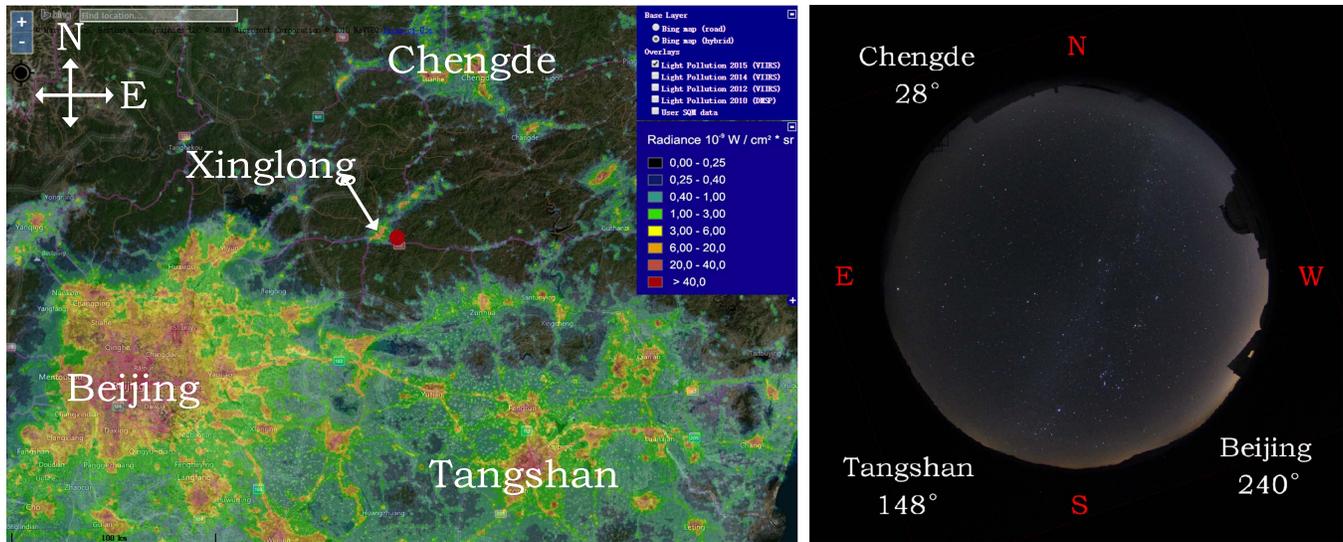


Figure 4. (left panel) Light pollution map showing the location of Xinglong Observatory (red dot) and main surrounding cities and towns. (right panel) Mirror-reflected All-sky Camera image.

(A color version of this figure is available in the online journal.)

Raw data were processed with the standard procedure, using various available tasks in Image Reduction and Analysis Facility (IRAF)⁵ and Interactive Data Language (IDL). Since the dark current of CCD is negligible, we corrected for bias and flat-field in object images. The raw frames are contaminated with lots of cosmic rays due to long exposure times. To remove the influence of cosmic rays on the spectra of objects and the night sky, we used the cosmic-ray rejection provided by Laplacian edge detection. For details on the algorithms and introductions this involves, see van Dokkum (2001). Figure 1 shows the image before and after cosmic-ray removal. The upper panel is the original spectrum and the lower panel is the corrected spectrum with no cosmic rays, which suggests that Laplacian edge detection works well for removing the cosmic rays.

We extracted the portion of the night sky spectrum in the same frame and same dispersion direction as the stellar spectrum. We selected the “night sky” part as far as possible from the stellar contribution in order to avoid contamination from stellar lines. We also looked carefully at the contribution from faint stars in the frames and removed them using the standard tasks available in IRAF. Since spectra of the objects in CCD have a slight dispersion curvature, we have performed the curvature correction to avoid errors in the wavelength calibration. We have performed flux calibration of observed spectroscopic standard stars and used it as a reference to calibrate the night sky spectrum. The final spectra were corrected for extinction using a local atmospheric extinction file. We converted the flux units to $\text{erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ for further analysis. Because we are also interested in the broadband of sky brightness, we have measured the magnitudes

in broadbands (Johnson system) B and V by convolving the night sky spectra with corresponding sensitivity curves.⁶

3. The Night Sky Spectrum and Its Results

The typical night sky spectrum of Xinglong Observatory is shown in Figure 2, and the emission lines from artificial and natural light sources are identified and marked. The artificial sources are known to be a mercury (Hg) vapor lamp, a low pressure sodium (Na) vapor lamp (LPS), and a high pressure sodium (Na) vapor lamp (HPS). Prominent Hg Γ lines are noticeable at 4047, 4358, 5461, 5770 and 5791 \AA , and weak lines of Hg Γ are noticed at 4078, 4827, and 4832 \AA . Na Γ emission lines at 4420, 4423, 4665, 4669, 4748, 4752, 4978, 4983, 5149, 5153, 6100, 6154, and 6161 \AA are weaker compared to stronger lines at 5683, 5688, 5890, and 5896 \AA . The strong Na emission lines in the region of 5500–5900 \AA have contributions from both LPS and HPS, whereas other Na lines are from HPS. Oxygen emission lines in our spectra are mainly concentrated at 5577, 6300, and 6364 \AA . OH molecule lines are mainly distributed in wavelengths redder than 6500 \AA .

We chose the data one hour after the end of evening astronomical twilight (when the Sun is 18° below the horizon), when the sky becomes completely dark, to estimate the night sky brightness and monitored the sky for the whole night in one hour intervals to see whether there are any changes in the sky brightness in a single observing dark night. The sky brightness obtained during 2007 is shown in Figure 3. The altitudes of the telescope pointings for all spectra are over 60° . We noticed a little decrement

⁵ IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.

⁶ <http://www.aip.de/en/research/facilities/stella/instruments/data/johnson-ubvri-filter-curves>.

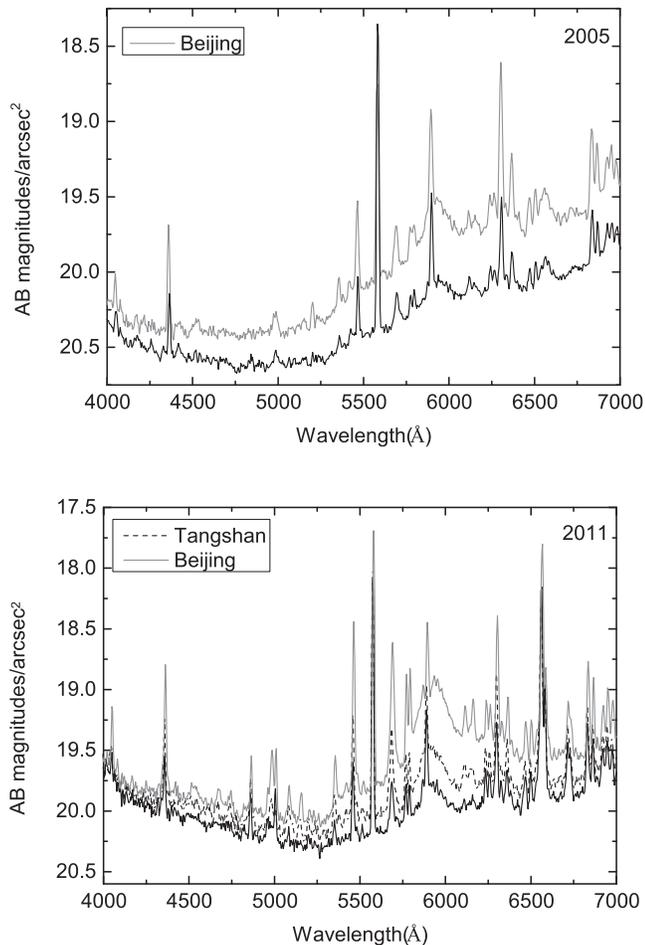


Figure 5. Comparison of night sky spectra at zenith with zenith distances around 50° toward the direction of Beijing in 2005. A similar comparison of Xinglong Observatory with zenith distances around 60° in the Beijing and Tangshan directions is shown for 2011.

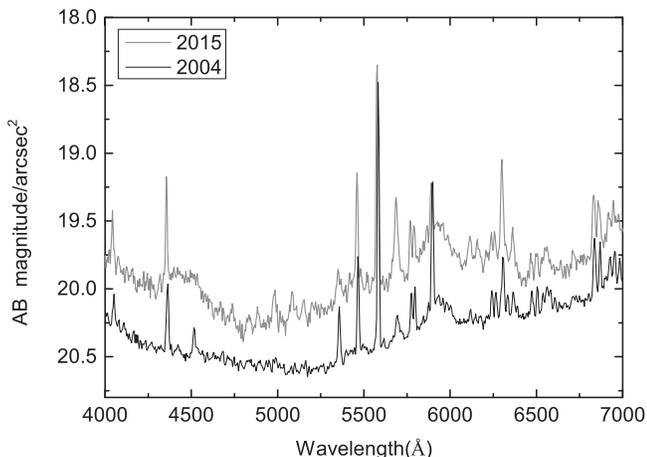


Figure 6. Comparison of the night sky spectra of Xinglong Observatory between 2004 and 2015.

in the sky brightness, but it was not significant. The same analysis for the data obtained during 2014 confirms a similar trend.

Figure 4 shows the locations of cities and towns around Xinglong Observatory in a light pollution map⁷ and an All-sky Camera image of Xinglong Observatory. Note that the bright night sky at larger zenith distances is mainly influenced by the surrounding cities. We performed a quantitative analysis to check the change in night sky brightness at different zenith distances and azimuthal directions and found that the night sky is brighter toward the southwest, where Beijing is located. The relative sky brightness between the zenith and a zenith distance around 50° toward Beijing direction is shown in Figure 5. For comparison, we have selected data toward Tangshan and show it along with that corresponding to Beijing in Figure 5. This analysis suggests that the influence of light pollution from Tangshan is relatively insignificant compared to that from Beijing. Since the town of Xinglong is located west of Xinglong Observatory and very close compared with other cities, we also found that Xinglong contributes significant light pollution to the images of the All-sky Camera.

In order to check the changes in night sky brightness at Xinglong Observatory over the past years, representative night sky spectra from 2004 and 2015 are shown in Figure 6 for comparison. We notice a significant increase in the sky brightness in 2015 compared with 2004. Since we are concerned with whether the night sky brightness has changed during all these years from 2004 to 2015, we have analyzed the spectra for all the years and show the sample spectrum from each year in Figure 7. We found that the night sky brightness has tended to increase from 2004 to 2015. Table 1 shows the night sky brightness in broadbands B and V during these years; these broadband values were convolved by the corresponding night sky spectrum. We also found that the zenith sky brightness over Xinglong Observatory increased slightly between 2004 and 2015. The zenith sky has brightened by about $0.5 \text{ mag arcsec}^{-2}$ in the B and V bands.

4. Conclusions

We have studied the night sky brightness at Xinglong Observatory using on spectroscopic measurements. Overnight monitoring of sky brightness suggests that the zenith night sky brightness decreases with time, but this decrease is not significant. We noticed strong emission lines from Hg I and Na I in the spectra, apart from natural light emission lines, indicating the influence of light pollution from the usage of mercury and sodium lamps in the cities surrounding Xinglong Observatory. The influence of light pollution from the direction of Beijing is stronger compared with that from the direction of Tangshan and other areas. We compared the night sky spectra for 12 years, from 2004 to 2015, and found a trend of increasing sky brightness

⁷ The use of data from www.lightpollutionmap.info should be credited to "Jurij Stare, www.lightpollutionmap.info", but because the original data is sourced from the Earth Observation Group of the NOAA National Geophysical Data Center, it should also be credited as such.

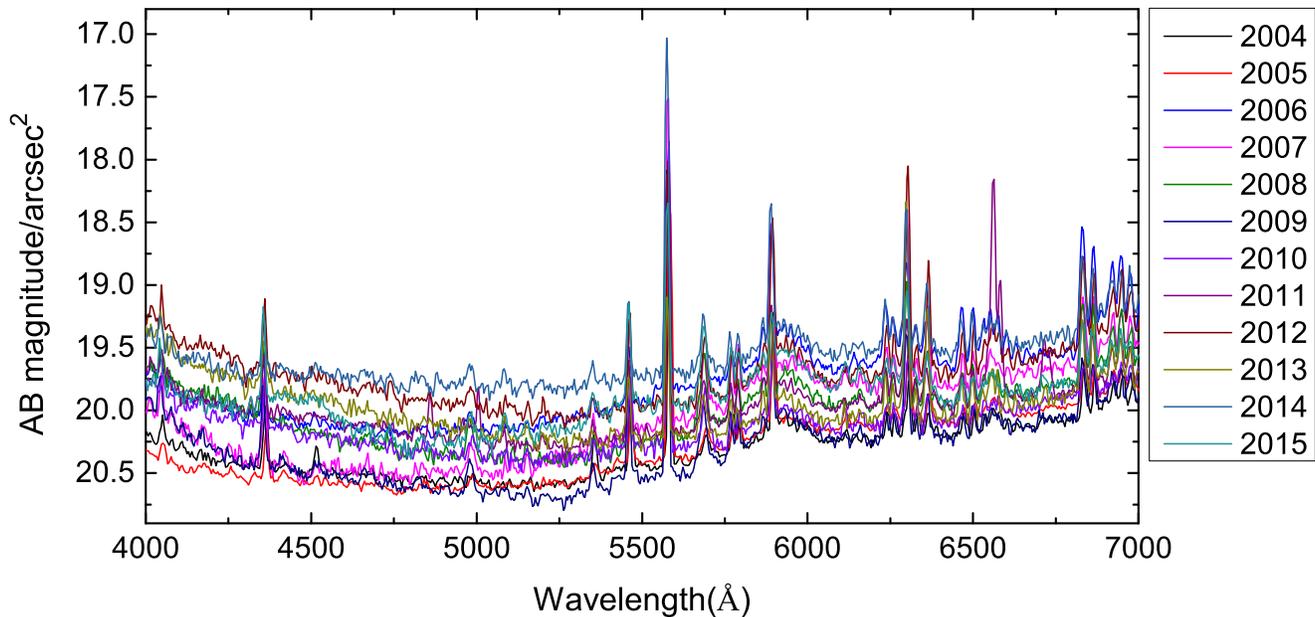


Figure 7. Sample night sky spectra of Xinglong Observatory over 12 years.
(A color version of this figure is available in the online journal.)

Table 1
Statistics of the Night Sky Brightness at Xinglong Observatory
from 2004 to 2015

Year	Broadband (mag arcsec ⁻²)	
	V	B
2004	20.35	20.37
2005	20.32	20.46
2006	19.80	19.91
2007	19.98	20.23
2008	20.11	19.91
2009	20.36	20.25
2010	20.17	20.02
2011	20.05	19.88
2012	19.90	19.68
2013	20.11	19.67
2014	19.56	19.59
2015	19.89	19.91

during the studied period. The convolution of broadband magnitudes suggests that the zenith sky has brightened by about 0.5 mag arcsec⁻² in the V and B bands. Consecutive spectroscopic measurements in the night sky brightness at Xinglong Observatory in the future will be essential, not only for monitoring purposes, but also for scientific reference.

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