NBS Narrow-Band Data Continuum Subtraction Batch Processing Method Postprint

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Abstract

Optical narrow-band observations can characterize the clear structures of emission-line objects and constitute an important tool for studying such objects, holding significant importance for research on star-forming regions, quasar narrow-line regions, galactic H II regions, interstellar medium, and related areas. Eliminating the continuum from narrow-band images is a commonly used method for searching for emission-line objects. Traditionally, the solution for continuum subtraction involves adjusting image alignment based on pixel position, direction, and intensity, followed by subtracting the two images; however, this process is cumbersome and unsuitable for continuum subtraction in large survey data. Based on [S II] band data from the narrow band survey (NBS) project, we propose a method that automatically matches broad-band and narrow-band flux data with stellar image profiles. This method automatically matches the astronomical positions of images, avoiding pixel position adjustments and image selection during the image pixel alignment process. By rapidly detecting flux and stellar images in broad-band and narrow-band images, it completes the corresponding matching and improves the efficiency of image subtraction. According to experimental results, approximately 70% of bright stars can be cleanly removed in continuum-subtracted images, and relatively clear structures of emission-line objects can be obtained. Currently, this method has been applied to work such as searching for Herbig-Haro objects (abbreviated as HH objects) and selecting supernova remnant candidates.

Full Text

The Batch Processing Method of Continuum Subtraction for Narrow Band Survey Data

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Abstract: Optical narrow-band observations can reveal the detailed structures of emission-line objects and serve as a crucial tool for studying star-forming regions, quasar narrow-line regions, galactic H II regions, and interstellar media. Continuum subtraction is a common method for identifying emission-line objects in narrow-band images. Traditionally, this process involves manually adjusting image alignment based on pixel position, orientation, and intensity before subtracting two images. However, this approach is cumbersome and unsuitable for large-scale survey data. Based on [S II] band data from the Narrow Band Survey (NBS), we propose an automated method for matching wide- and narrow-band flux data and point spread functions. This method automatically aligns images astrometrically, avoiding pixel-level adjustments and manual image selection during the alignment process. By rapidly detecting flux and stellar profiles in both wide- and narrow-field images, the method completes the corresponding matching and improves the efficiency of image subtraction. Experimental results show that approximately 70% of bright stars can be cleanly removed from the continuum-subtracted images, while preserving clear structures of emission-line objects. This method has already been applied to searches for Herbig-Haro (HH) objects and supernova remnant candidate selection.

Keywords: narrow-band survey; continuum subtraction; sky background subtraction; image data processing

1 Introduction

Over recent decades, large-scale multi-band photometric and spectroscopic surveys covering the Milky Way and even the entire sky have been successively carried out. Optical narrow-band imaging observations can obtain emission-line intensities, providing physical properties such as temperature, elemental abundance, and galaxy redshift, which are significant for studying shock emission sources, supernova remnants, H II regions, and planetary nebulae [1]. Most existing narrow-band surveys have focused on Hα observations. Surveys with angular resolution of several arcminutes are represented by SHASSA [2] (The Southern H-Alpha Sky Survey Atlas) and VTSS [3] (The Virginia Tech Spectral-Line Survey). Higher spatial resolution Hα surveys include the SHS [4] (Southern Halpha Survey) conducted by the Anglo-Australian Observatory in 1997, which covered a 5.5° × 5.5° field of view with spatial resolution reaching 1 –2 , completed in 2003. Subsequently, the IPHAS [5] (The INT Photometric Hα Survey of the Northern Galactic Plane) was launched with a smaller telescope field of view of 34 × 34 and spatial resolution of about 1.7 , observing approximately 1,800 square degrees of the northern Galactic plane within a 10° latitude range. WHAM [6] (The Wisconsin H-Alpha Mapper Survey) completed Hα narrow-band coverage of three-quarters of the sky at declinations above -30°. In addition to these narrow-band surveys, PTF [7] (The Palomar Transient Factory) also completed Hα narrow-band coverage of three-quarters of the sky at declinations above -25°. Detailed information about these projects is provided in Table 1 .

Continuum subtraction is an essential step in narrow-band image data processing, as it visually reveals emission-line object information in narrow-band images and facilitates the search for various emission-line object candidates. Traditional continuum subtraction for narrow-band data requires manual adjustment of stellar image alignment, involving image rotation, flipping, and manual selection of stars for flux calibration. Early studies even relied on visual comparison between continuum and narrow-band data, such as Bally et al.'s 1995 study of HH bipolar jets and molecular outflows in the L1228 region [8] and Wang et al.'s 2003 observations of HH objects in the OB1 molecular cloud [9], both of which introduced human factors into target identification. Later continuum subtraction work required first determining the target region before performing subtraction, as seen in Blair and Long's 2004 optical observations of supernova remnants in M83 [10] and Long et al.'s 2019 observations limited to NGC 6946 [11]. While feasible for small sky areas and specific targets, this approach becomes cumbersome for large survey datasets and multi-region observations, making candidate selection tedious. Therefore, this paper proposes a batch automated continuum subtraction method that improves efficiency compared to traditional approaches. Through batch continuum subtraction, we can uniformly search for candidate emission-line objects from the subtracted images.

Section 2 introduces the NBS survey system, including the observatory site, instrumentation, progress, and data characteristics. Section 3 describes the image data processing workflow, focusing on continuum subtraction. Section 4 provides a summary.

2 Overview of the NBS Survey

The Narrow Band Survey (NBS) is a narrow-band survey project targeting the northern Galactic plane, conducted using the China Near Earth Object Survey Telescope (CNEOST) at the Xuyi Observatory Station of Purple Mountain Observatory, Chinese Academy of Sciences. The telescope employs a Schmidt optical system with a 120 cm primary mirror at F/1.8 and a 104 cm Schmidt corrector plate. It is equipped with a 104 × 104 CCD camera with 13.9 m pixels, corresponding to 1.028 per pixel on the sky, covering a 3° × 3° field of view per frame (referred to as a sub-field). NBS observes each sub-field five times per lunar cycle (on the 15th day and the two days before and after), with each exposure lasting 180 s.

To avoid poor imaging quality at the edges of the large field of view, adjacent sub-fields are observed with partial overlap. As shown in Figure 1 [Figure 1: see original paper], nine sub-fields are observed, with stars marking the central positions and gray areas representing the overlapping regions. The overlap width is 1°, effectively dividing the 3° × 3° field of view into nine sections. The eight peripheral sections are overlap regions, where areas 1°–1.5° from a sub-field center are covered by adjacent sub-field centers at 0.5°–1°, yielding high-quality 2° × 2° fields.

The NBS system currently employs [S II], Hα, and [O III] filters. The filter transmission curves are shown in Figure 2 [Figure 2: see original paper], with specific parameters listed in Table 2 . Since the continuum data used in this work are r-band images from the Xuyi Observatory, Figure 2 also includes the Xuyi r-band transmission curve, which has a central wavelength of 6,240 Å and bandwidth of 2,500 Å. NBS covers the northern Galactic plane ($-5° < b < +5°$, $29° < l < 215°$), approximately 1,800 square degrees. Since 2016, first-epoch observations in the [S II] and Hα bands have been essentially completed, while [O III] band observations are ongoing. Figure 3 [Figure 3: see original paper] shows the [S II] band data coverage, with red boxes indicating observed fields, dashed lines representing the Milky Way, and high-latitude coverage representing the Extended NBS (ENBS).

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3 Data Processing Workflow

The data processing workflow includes image preprocessing, astrometric calibration, photometry, flux calibration, continuum subtraction, and catalog generation with narrow-band imaging. This paper focuses on flux calibration and continuum subtraction.

3.1 Image Preprocessing

Image preprocessing includes overscan/bias correction, super flat-fielding, cosmic ray removal, and bad pixel masking. After preprocessing, the central 2° × 2° region is extracted as the target image. Figure 4 [Figure 4: see original paper] shows a comparison between a raw single image and the preprocessed result.

Astrometric calibration is performed using the SCAMP software with the UCAC-4 catalog, which provides high-precision astrometric data for 113,780,093 objects covering V and R bands from 8 to 16 mag [12]. The positional calibration accuracy is approximately 0.2 . Figure 5 [Figure 5: see original paper] shows the error statistics in right ascension and declination: $\Delta\alpha$ = -0.02 ± 0.20 and $\Delta\delta$ = -0.02 ± 0.15 , which determines the precision of subsequent continuum subtraction.

3.2 Photometry and Flux Calibration

Given that NBS targets dense stellar fields, we employ both aperture photometry and point spread function (PSF) photometry. While aperture photometry works well for isolated sources, PSF photometry is more accurate in crowded fields.

Flux calibration establishes a scaling relationship between instrumental flux and the standard system to convert instrumental magnitudes to standard magnitudes. Since no standard stars exist in the [S II] band, we cannot directly obtain standard fluxes or scaling factors. We propose a method to construct standard stars using LAMOST spectroscopic data: first, correct LAMOST instrumental fluxes to standard fluxes, then convolve the corrected fluxes with the [S II] band response curve to obtain [S II] standard fluxes, enabling calculation of [S II] magnitudes and construction of a [S II] standard star catalog.

The procedure is as follows: 1. **Data preparation**: Match source positions in NBS images with the LAMOST and IPHAS catalogs to identify common targets. Select sources classified as stars (to avoid quasars), with signal-to-noise ratio > 30, and F-type stars brighter than 15 mag. Save the LAMOST flux data and IPHAS r-band magnitudes. 2. **Convert LAMOST relative flux to standard flux**: IPHAS r-band magnitudes provide standard r-band fluxes. Convolving LAMOST instrumental flux with the IPHAS r-band response curve yields LAMOST relative flux in the r band. The ratio between r-band standard flux and instrumental flux gives the calibration constant, which is then applied to convert LAMOST instrumental flux to standard flux across the r band. 3. **Calculate [S II] band standard flux**: Since the NBS [S II] filter wavelength range falls entirely within the r-band range (Figure 6 [Figure 6: see original paper]), we can use the LAMOST r-band standard flux. The [S II] band standard flux is obtained by convolving the LAMOST r-band standard flux with the [S II] band response curve. 4. **Calculate [S II] magnitudes and construct the standard star catalog**.

Photometric accuracy after flux calibration is shown in Figure 7 [Figure 7: see original paper]. Figure 7a shows the magnitude and error distribution from a single 180 s [S II] exposure, reaching a limiting magnitude of ~17.5 mag at 5σ. Figure 7b shows the distribution from 900 s of exposure (five co-added 180 s images), achieving a 5σ limiting magnitude of 18.3 mag, meeting the design requirement of 18.5 mag at 5σ.

Constructing [S II] band standard stars enables flux calibration of [S II] images for subsequent emission-line object flux measurements. This method improves narrow-band flux calibration precision, providing the basis for measuring fluxes of emission-line objects after continuum subtraction. For flux-calibrated wide-and narrow-band images, the residual image after subtraction represents the flux-calibrated result, allowing direct photometry of emission-line objects.

3.3 Continuum Subtraction from [S II] Narrow-Band Images

Continuum subtraction typically uses r-band images as the continuum reference [13]. This work employs r-band data from the Xuyi Observatory as continuum data. Calculations show that [S II] emission contributes only 0.25% to the total r-band flux, making its contribution negligible when subtracting r-band images from [S II] narrow-band images.

3.3.1 Sky Background Subtraction Night sky background exhibits spatial gradients that cannot be ignored for large-field survey telescopes. Therefore, narrow-band images must first have sky background information removed. We obtain the sky background by subtracting bright sources from the image, using Source Extractor (hereafter SE) software. Bright sources are defined as those exceeding the SE detection threshold, typically set to 3σ. SE provides source detection, integrated detector counts, and stellar profile information. Figure 8 [Figure 8: see original paper] illustrates the sky background subtraction process:

1. **Obtain bright source positions**: Configure SE to output a segmentation map where bright source positions retain their counts and other positions are set to 0 (Figure 8b).
2. **Remove bright sources**: Process the segmentation map by setting bright source pixels to 0 and background pixels to 1, then multiply with the original image to remove bright source information.
3. **Extract sky background**: Apply median smoothing to the bright-source-removed image. For large-scale images like NBS, increase the smoothing scale to eliminate large-amplitude background variations; we use a 500 pixel × 500 pixel smoothing scale. The resulting sky background is shown in Figure 8c, which yields a relatively uniform background for images without nebulae, avoiding nebula removal.
4. **Subtract sky background**: Subtract the background image from the original to obtain the background-subtracted image (Figure 8d).

NBS images cover the Galactic plane and often contain nebulae, making nebula extraction challenging. We address this by lowering SE's DETECT_{THRESH} parameter while increasing DETECT_{MINAREA} to capture more bright nebula information while reducing noise. Figure 8e shows an [S II] image with nebulae, and Figure 8f shows the background extracted using the above method. The upper-right corner appears brighter due to residual nebula information. Using this directly for background subtraction would remove some nebula information. For such cases, we select regions without nebulae or with faint nebulae (red boxes in Figure 8f) to perform background fitting. Figure 8g shows the fitted background derived from the region within the red box in Figure 8f.

3.3.2 Continuum Subtraction To improve signal-to-noise ratio, both background-subtracted images are median-smoothed before continuum subtraction, making shock structures clearer. Continuum subtraction requires accurately calculating flux scaling factors and PSF matching factors for identical sources in both bands. The flux scaling factor is relatively straightforward to obtain. PSF matching aims to align source sizes between the two images; smaller sources are expanded to match larger ones using a Gaussian filter G(0, σ), where σ is the PSF matching factor. Since the full width at half maximum (FWHM) of a stellar image is proportional to the Gaussian σ, the relationship is:

$$\mathrm{FWHM} = 2\sqrt{2\ln(2)}\sigma$$

Adjusting the FWHM enables control of stellar image size. The continuum subtraction workflow is shown in Figure 9 [Figure 9: see original paper], with the process illustrated in Figure 10 [Figure 10: see original paper]. The steps are:

1. **Data preparation**: Use SE to perform photometry on both band images, obtaining coordinates, FWHM, and flux information.
2. **PSF matching**: Plot FWHM distribution histograms for both bands and fit them with Gaussian functions to determine the peak values (of the Gaussian distribution), denoted as FWHM_1 and FWHM_2. Calculate σ_1 and σ_2 using the above equation, assuming $\sigma_1 > \sigma_2$. The PSF matching factor σ is then:

   $$\sigma = \sqrt{\sigma_1^2 - \sigma_2^2}$$

   Apply this factor as a Gaussian convolution kernel to the original image to complete PSF matching.
3. **Flux matching**: Perform photometry on the PSF-matched images, divide the fluxes of corresponding sources to obtain flux scaling factors for each source, plot the distribution histogram, and fit it with a Gaussian function. The peak value ( ) gives the flux scaling factor, which is multiplied with the original data to match flux values.
4. **Continuum subtraction**: Use SWARP software to subtract the two images. SWARP matches images using WCS coordinates, avoiding manual pixel adjustment and image rotation, enabling fast processing of large datasets. The r-band image is negated, then SWARP sums the matched images to complete continuum subtraction.

The result is shown in Figure 10e, where clear filamentary structures are visible within the red boxes. These structures are prominent in the [S II] narrow-band image but not obvious in the Xuyi r-band image. After batch processing continuum subtraction, we can obtain clear shock structures from [S II] images. Photometry on images before and after continuum subtraction detects 63,500 sources in the original [S II] image and over 18,000 sources after subtraction, removing approximately 70% of stars. Figure 11 [Figure 11: see original paper] shows the stellar distribution in a local region of 2,000 × 2,000 pixels (the full image is 7,000 × 7,000 pixels), demonstrating that most stars are removed in the processed local image.

Since images contain various stellar types with different matching factors between wide and narrow bands, non-emission-line stars cannot be completely removed. However, our goal is to rapidly identify emission-line objects with extended or filamentary structures from massive image datasets. Incomplete removal of individual bright sources does not significantly impact the search for extended emission-line objects. This method has been applied to searches for HH objects and supernova remnant candidate selection, with the process shown in Figure 12 [Figure 12: see original paper].

4 Summary

Based on [S II] band data from the Narrow Band Survey, this paper proposes an automated method for matching flux data and stellar profiles across different bands to achieve batch continuum subtraction for large-field [S II] images. We utilize SWARP and Source Extractor software: SWARP automatically matches astronomical positions between images, avoiding manual pixel alignment and image rotation, while Source Extractor rapidly detects flux and stellar profiles in wide- and narrow-band images. By performing histogram statistics on flux and profile values, we obtain scaling factors for flux and PSF matching. Finally, SWARP performs batch image subtraction, significantly improving efficiency over traditional methods. Experimental results show that approximately 70% of bright stars can be cleanly removed, while preserving clear structures of emission-line objects. Our goal is to rapidly identify emission-line objects with extended structures from massive datasets; incomplete removal of individual bright sources does not substantially affect this search. After initial candidate selection, more refined image processing or precise flux measurements can be performed. This method has been applied to searches for HH objects and supernova remnant candidate selection.

Current limitations include: (1) For images containing large-scale nebulae, some nebula information remains in the extracted background. Our method of using small background regions avoids removing nebula information but reduces background accuracy and continuum subtraction precision. (2) Different stellar types have different matching factors between wide and narrow bands, preventing complete removal of non-emission-line stars. (3) PSF matching is imperfect for some bright sources. Future work will address these issues to further optimize and improve the method.

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Note: Figure translations are in progress. See original paper for figures.