The Stellar Abundances and Galactic Evolution Survey (SAGES) III Postprint

Authors: Chun Li, Zhou Fan, Gang Zhao, Wei Wang, Jie Zheng, Kefeng Tan, Jingkun Zhao, Yang Huang, Haibo Yuan, Kai Xiao, Yuqin Chen, Haining Li, Yujuan Liu, Nan Song, Ali Esamdin, Hu-Biao Niu, Jin-Zhong Liu and Guo-Jie Feng

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Abstract

The Stellar Abundances and Galactic Evolution Survey (SAGES) is a multi-band survey that covers the northern sky area of 12,000 deg2. The Nanshan One-meter Wide-field Telescope (NOWT) of the Xinjiang Astronomical Observatory carried out observations on g/r/i bands. Here, we present the survey strategy, data processing, catalog construction, and database schema. The observations of NOWT started in 2016 August and were completed in 2018 January, a total of 17,827 frames were obtained and 4600 deg2 sky areas were covered. In this paper, we release the catalog of the data in the g/r/i bands observed by NOWT. In total, there are 109,197,578 items of source records. The catalog is the supplement for the SDSS for the bright end, and the combination of our catalog and these catalogs could be helpful for source selections for other surveys and Milky Way sciences, e.g., white dwarf candidates and stellar flares.

Full Text

Preamble

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The Stellar Abundances and Galactic Evolution Survey (SAGES) III
Jingkun Zhao[1], Yang Huang[1], Chun Li[1], Gang Zhao[1,2], Wei Wang[1], Kefeng

Tan[1], Zhou Fan[1,2], Jie Zheng[1], Haibo Yuan[2], Kai Xiao[1,2], Yuqin Chen[1], Haining Li[1], Yujuan Liu[1], Nan Song[1,3], Ali Esamdin[4], Hu-Biao Niu[4], Jin-Zhong Liu[4], and Guo-Jie Feng[4]

[1] CAS Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China; lichun@nao.cas.cn, zfan@nao.cas.cn, gzhao@nao.cas.cn

[2] School of Astronomy and Space Science, University of Chinese Academy of Sciences, Beijing 100049, China

4 Xinjiang Astronomical Observatory, Urumqi 830011, China

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Abstract

The Stellar Abundances and Galactic Evolution Survey (SAGES) is a multi-band survey covering approximately 12,000 deg^2 of the northern sky. Observations in the g/r/i bands were conducted using the Nanshan One-meter Wide-field Telescope (NOWT) of the Xinjiang Astronomical Observatory. This paper presents the survey strategy, data processing pipeline, catalog construction methodology, and database schema. NOWT observations began in August 2016 and concluded in January 2018, yielding 17,827 frames and covering approximately 4,600 deg^2 of sky. We release the catalog of g/r/i band observations from NOWT, comprising 109,197,578 source records. This catalog supplements SDSS at the bright end, and the combined dataset will be valuable for source selection in other surveys and for Milky Way science, including white dwarf candidate identification and stellar flare studies.

Key words: surveys –catalogs –techniques: photometric

1. Introduction

Astronomy is fundamentally an observational science, and wide-field sky surveys are essential for studying the structure and evolution of the Galaxy. In recent decades, numerous discoveries have emerged from major survey projects such as Gaia, LAMOST, GSC, and 2MASS. SkyMapper, a southern sky survey, has proven efficient at identifying metal-poor stars. Motivated by this success, we initiated the Stellar Abundances and Galactic Evolution Survey (SAGES) for the northern sky region.

SAGES is a multi-band survey of the northern sky. The Nanshan One-meter Wide-field Telescope (NOWT) at the Xinjiang Astronomical Observatory (XAO), Chinese Academy of Sciences (CAS), performed observations in the g/r/i passbands. Here we present the survey strategy, data processing, catalog construction, and database schema. NOWT observations began in August 2016 and were completed in January 2018, obtaining 17,827 frames and covering approximately 4,600 deg^2.

SAGES is a northern sky photometric survey with eight passbands, designed primarily to search for metal-poor stars in the Galaxy (Fan et al. 2023). The survey aims to derive stellar atmospheric parameters for several hundred million stars.

The SAGES photometric system is unique and defined by our team, comprising eight bands (us/vs/g/r/i/αn/αw/DDO51) that include narrow-band, intermediate-band, and broad-band filters. The survey covers the northern sky region with declination $\delta > -5°$, avoiding the Galactic disk region ($-10° <$ b $< +10°$) to prevent saturation and image contamination from excessively bright stars. The designed survey area exceeds 12,000 deg^2 (approximately 60% of the northern sky). Since operations began in 2016, data have been obtained for five bands. The us and vs band catalogs have been released by Fan et al. (2023). The g/r/i bands were observed by NOWT, covering 4,254 sky areas and acquiring 17,827 frames. After data reduction, photometry, calibration, and combination, 51,149,452 sources were detected. The completeness magnitudes for the g/r/i passbands are 19.2 mag, 19.1 mag, and 18.2 mag, respectively. This dataset has been released and is available on the China-VO platform.

This paper provides an overview of the Nanshan g/r/i band observations within SAGES. Section 2 describes the project background, Section 3 details the observations, Section 4 explains the data reduction process, Section 5 presents data quality assessments, and Section 6 offers a summary and future plans.

2.1. The Photometric System of SAGES

Figure 1 [Figure 1: see original paper] and Table 1 present details of the eight SAGES passbands. The us band is similar to the Strömgren-Crawford (SC) system, covering the Balmer jump, while vs is a custom-developed filter covering the Ca II H&K absorption lines, which are highly sensitive to stellar metallicity. These two passbands are therefore effective for identifying metal-poor stars. The g/r/i bands match the SDSS passbands, which are useful for estimating stellar effective temperatures (Teff). The SAGES g/r/i observation plan aims to complete full northern sky coverage in combination with the SDSS catalog.

The DDO51 band is sensitive to the surface gravity of late-type stars. The αn and αw bands are used to estimate interstellar extinction, as the αw $-$ αn color is sensitive only to Teff and independent of interstellar extinction, allowing for more accurate temperature constraints. The difference between these colors and Teff then constrains extinction. DDO51 measures the MgH feature in K-M dwarfs (Bessell 2005). For further details about SAGES, please refer to Fan et al. (2023).

2.2. The Overall Observation Progress of the SAGES Project

Observations of the eight SAGES bands are conducted at different telescopes and sites. The us and vs bands are observed at Kitt Peak National Observatory (KPNO) in Arizona, USA, using the 90-inch Bok telescope. Due to limited observation time from February to August and weather constraints, the sky area with right ascension $12 < \alpha < 18$ hr is not included in the survey. The u/v passband data have been released by Fan et al. (2023).

Observations of the g/r/i passbands were carried out by NOWT from August 2016 to January 2018, with partial data introduced in this paper. For the DDO51, αw, and αn passbands, multiple telescopes were planned, including the 1 m Zeiss telescope at the Maidanak Astronomical Observatory (MAO, 66°53 47 E, 38°40 22 N) of the Ulugh Beg Astronomical Institute (UBAI), Uzbekistan (Kardopolov & Filip' ev 1979), and the Xuyi 1 m Schmidt telescope of the Purple Mountain Observatory (PMO) of CAS. DDO51 passband observations with NOWT are ongoing. The full sky coverage of SAGES will be completed over three years (2023–2026).

2.3. Observatory and Telescope

NOWT belongs to XAO, CAS, and is located at Nanshan Observatory (87°10 30 E, 43°28 25 N), approximately 75 km from Urumqi city at an altitude of 2,088 meters (Bai et al. 2000). The site has more than 300 observable nights per year, with over 210 clear nights. The seeing distribution peaks around 1.67, with 80% of nighttime values below 2.2. At zenith, the V-band sky brightness is approximately 21.7 mag arcsec^{-2} (Bai et al. 2000).

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NOWT is a one-meter telescope with an Alt-Az mount operating at prime focus with a field corrector. The parabolic primary mirror has an effective diameter of 1 m and a focal length of 2,159 $\pm$ 20 mm (Bai et al. 2000). Pointing accuracy is better than 3 (rms error), and tracking accuracy is 1.8 rms over 60 minutes (Bai et al. 2000). Overall, 80% of the collected energy is concentrated within a circle of diameter less than 1.15 across a field diameter of 2.4°. After pointing model correction, the telescope' s pointing accuracy is better than 5 rms for each axis (Liu et al. 2013; Bai et al. 2000). NOWT provides excellent optical quality for photometry, greatly benefiting SAGES.

2.4. Detectors of Nanshan g/r/i Observation

The g/r/i passband filters used in NOWT for SAGES were manufactured by Custom Scientific, Inc., USA, following the standard SDSS system. The CCD camera installed on NOWT has 4,096 $\times$ 4,136 pixels and was designed and integrated by the CCD laboratory of NAOC (Bai et al. 2000). The camera is placed at the prime focus of the telescope and cooled by liquid nitrogen. It has four amplifiers for fast readout, as shown in Figure 2 [Figure 2: see original paper]. The physical pixel size is 12 × 12 m, providing a field of view of 1.3° × 1.3° and a pixel scale of 1.124 (Bai et al. 2000). For overscan correction, as shown in Figure 2, 32-pixel columns are set as overscan pixels for each amplifier to correct image bias.

2.5. Observations

The planned survey area was described in Section 1. The g/r/i bands aim to complete the sky area coverage of both the SDSS survey and SAGES. Due to NOWT' s latitude and location, only sky areas with declination > 5° were observed.

2.6. Observing Strategy and Coverage

NOWT' s field of view is approximately 1.3° × 1.3°, so we designed each survey field as 1.04° × 1.04°. The planned ~4,600 deg^2 survey area was divided into 4,254 blocks for observation. Fields at the same declination form a stripe, and adjacent five fields are combined as a survey block to minimize long movements between blocks. Overlap between neighboring fields aids flux calibration and ensures complete sky coverage. Each field is named with an integer sequence. Since SDSS already covered a large area of the southern sky, we only needed to complete the remaining regions. The NOWT blocks are displayed in Figure 3 [Figure 3: see original paper].

We developed a strategy pipeline to generate observation scripts for each night. The pipeline ensures no duplicate observations of any field, selects appropriate blocks based on observation date, excludes fields near the Moon, and sorts blocks to minimize airmass. The pipeline also provides animated observation progress displays for monitoring. If observations are interrupted by bad weather or other targets, the pipeline report helps operators resume from the proper position.

3.1. Image Correction

Our team built a pipeline for photometry and astrometry. The data correction procedure includes overscan correction, bias combination, flat-field combination, and survey image correction. Twilight flats are used for correction in NOWT runs. For overscan correction, the median value of each row is subtracted. For bias correction, we take a set of 10 bias images before and after observation and use the median for correction. All survey images and flat-field images then undergo bias removal. For flats, a set of 10 sky flat frames per band is taken before and after observation when weather permits. After bias removal, flat images are normalized and combined using median values. Survey images are processed through overscan correction, bias removal, and flat-field correction. The numbers of corrected images are 5,283 frames in g band, 4,849 in r band, and 5,314 in i band.

Figure 2 [Figure 2: see original paper] shows the Andor 4k × 4k NOWT CCD array with four amplifiers. The right side displays the overscan area.

3.2. Flux Calibration

Xiao et al. (2023a) utilized both the spectroscopy-based Stellar Color Regression method (SCR method; Yuan et al. 2015) and the photometric-based SCR method (SCR method) to construct approximately 2.6 million dwarf standard stars, achieving an accuracy of about 0.01–0.02 mag per band. They then performed relative photometric calibration of NOWT' s g/r/i band imaging data. Absolute calibration was conducted using corrected Pan-STARRS DR1 (PS1) photometry by Xiao & Yuan (2022) and Xiao et al. (2023b), establishing the transformation relationship between calibrated magnitudes from NOWT and corrected PS1 magnitudes.

Comprehensive analysis of repeated sources in adjacent images revealed remarkable internal consistency of approximately 1–2 mmag across all filters. Using synthetic photometry with Gaia DR3 BP/RP spectra, PS1 magnitudes were synthesized, resulting in photometric calibration uniformities of approximately 2.4 mmag, 2.3 mmag, and 0.9 mmag for the g/r/i bands, respectively, within each 1.3° diameter field. During photometric calibration, the dependence of CCD gain and stellar flat on observation time was discussed, along with CCD position-dependent residuals of stellar flat correction. Further details can be found in Xiao et al. (2023a) and Fan et al. (2023).

4. Data Quality

In the Nanshan dataset, the numbers of g/r/i passband images used in calibration were 5,096, 4,551, and 5,153, respectively. The total number of survey images is 14,800. The total sources detected are 31,894,325 in g band, 38,711,424 in r band, and 38,531,820 in i band. After combining all sources, we have 51,149,452 sources in total, of which 21,819,140 were detected in all three g/r/i passbands.

4.1. Astrometry Precision

Figure 4 [Figure 4: see original paper] presents typical astrometric errors from one g-band frame named n8037.0172. External astrometric errors are estimated by comparing coordinate differences between this typical image and the reference PS1 catalog. The rms differences (calculated from all detected sources) are 0.28 for g band, 0.29 for r band, and 0.30 for i band, which are sufficient for WCS and astrometry.

4.2. The Limiting Magnitudes

Figure 5 [Figure 5: see original paper] shows a typical magnitude versus photometric error diagram for the r band. Photometric errors are derived from

Poisson statistics and do not include calibration errors. The limiting magnitude at S/N 10 (uncertainty of 0.1 mag) is approximately 19.0. Scatter is due to local background fluctuations from nearby source contamination and non-uniform sky background.

The limiting magnitudes reach 16.57, 16.46, and 15.49 mag in g/r/i bands, respectively, at 0.01 mag uncertainty (Poisson error only, excluding flux calibration errors). We calculated limit magnitudes using all frames and adopted median values per band. The limiting magnitudes at 0.2 mag uncertainty (corresponding to S/N = 5) are 20.19, 20.03, and 19.18, respectively. Figure 6 [Figure 6: see original paper] shows the limit magnitude distribution for all g-band fields at S/N = 100, corresponding to 0.01 mag photometric error.

Figure 7 [Figure 7: see original paper] displays the magnitude distribution for g/r/i passbands. From the diagram turning points, the completeness magnitudes are 19.2, 19.1, and 18.2 mag for g/r/i, respectively, demonstrating the observation depth.

Figure 8 [Figure 8: see original paper] shows the magnitude distribution for all Nanshan run sources across observed g/r/i fields. The x-axis represents magnitude range and the y-axis shows photometric counts. Peaks occur at g 19.2 mag, r 19.1 mag, and i 18.2 mag, corresponding to the completeness magnitudes for the Nanshan SAGES observations.

5. Data Access

SAGES g/r/i data have been released and are available on the China-VO platform and the National Astronomical Data Center (NADC) at https://nadc.china-vo.org.

6. Summary and Future Plans

This paper presents part of the full SAGES project: the observing strategy, observations, data reduction, and catalog production for the g/r/i passbands processed with NOWT. Some data reduction and calibration steps will be upgraded, such as fringe removal for i-band images, which we hope will improve photometry and calibration to provide deeper detection and more precise data. Observations of other SAGES passbands (DDO51 and αw) will be completed in the coming years. Future SAGES work will include additional passbands, more images, and improved sky coverage.

Zhou Fan
Wei Wang
Jie Zheng
Kefeng Tan
https://orcid.org/0000-0002-6790-2397
https://orcid.org/0000-0002-9702-4441

https://orcid.org/0000-0001-6637-6973
https://orcid.org/0000-0003-0173-6397

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ORCID iDs

https://orcid.org/0009-0000-4835-7525 Chun Li

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