Postprint: Survey for Variable Stars in Multiple Fields Near the Galactic Plane

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Abstract

Through meticulous data mining of historical observational data from the Nanshan One-meter Wide-field Telescope (NOWT) at the Xinjiang Astronomical Observatory (XAO), we have discovered over one hundred variable sources. The data processing pipeline employed is the XAO time-domain survey data processing package, which simultaneously accounts for internal weights and correlations within the photometric system and is implemented using a fast hybrid algorithm. In addition to known variable sources, we have identified numerous new variable sources. During the identification process for these new sources, we cross-matched our results with catalogs including LAMOST, GCVS, VSX, and Gaia DR2. In the discussion section, we provide detailed explanations regarding the utilization of each catalog. For the new sources, we ultimately found that the vast majority are eclipsing binaries, a small fraction are pulsating variables, and one exhibits relatively complex variability behavior.

Full Text

Variable Star Searching in Several Fields Near the Galactic Plane

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Abstract

We conducted detailed data mining of historical observations from the Nanshan One-meter Wide-field Telescope (NOWT) at the Xinjiang Astronomical Observatory (XAO) and discovered over a hundred variable sources. The data processing pipeline is the XAO time-domain survey data processing package, which simultaneously accounts for internal weighting and correlations within the photometric system and is implemented using a fast hybrid algorithm. Excluding known variables, we discovered many new ones. In the process of identifying these new variables, we cross-matched our results with catalogs including LAMOST, GCVS, VSX, and Gaia DR2. In the discussion section, we provide an explanation of the usage of each catalog. Among the new sources, we found that the vast majority are eclipsing binaries, a small fraction are pulsating variables, and one exhibits relatively complex behavior.

Keywords: time-domain survey; eclipsing binary stars; pulsating variable stars

1. Introduction

In optical astronomy research, targets with varying photometric flux are typically referred to as variable sources or variable stars. According to the classification rules of the *General Catalogue of Variable Stars 5.1* (GCVS 5.1) [1], these are categorized into eruptive, pulsating, rotating, cataclysmic, eclipsing binary, high-energy X-ray binary, and other types. In terms of formation mechanisms, there are variables caused by intrinsic mechanisms, such as the pulsating variable series including classically radially pulsating Cepheid variables [2] and RR Lyrae stars [3], as well as non-radial Scuti variables [4]. There are also variables caused by extrinsic mechanisms, such as those where the observed brightness changes due to the motion of stellar systems or occultation by neighboring companions or celestial bodies. Among currently known variable sources, eclipsing binary systems [5, 6], Scuti, and RR Lyrae stars constitute relatively high proportions. Additionally, although exoplanet transit events represent a small proportion among known variable sources, they have attracted considerable attention in astronomical research due to their unique nature. The well-known Kepler project and related joint observations [7] have yielded abundant research results, and searches for exoplanet systems are favored in numerous astronomical observations. The Nanshan One-meter Wide-field Telescope at the Xinjiang Astronomical Observatory’ s Nanshan Station, in collaboration with Nanjing University, conducted a survey searching for exoplanets in nearby fields. These observations generated a large amount of data, which we have analyzed in detail for variable star targets, aiming to mine a larger sample of variables and identify any unusual ones.

2. Telescope and Observations

The Nanshan One-meter Wide-field Telescope is located at the Nanshan Station of the Xinjiang Astronomical Observatory (longitude: 87.174°E, latitude: 43.473°N, altitude: 2088 m). The telescope truss is an alt-azimuth prime-focus design with a primary mirror effective aperture of 1000 mm and a focal ratio of f/2.2. The detector is an E2V CCD203-82 blue-sensitive chip with 4096 × 4136 pixels, a pixel scale of 1.125 /pixel, and a CCD field of view corresponding to 78 × 78 on the sky. The filter system is the Johnson UBVRI system.

The observation objective was to discover exoplanet candidates. When making the observation plan, we considered that the fields needed to contain a sufficient number of sufficiently bright targets, so we selected four fields near the Galactic plane (longitude: 166°, latitude: +7°) that were relatively dense yet with well-separated stars. To improve the sampling rate during observations, we used a single V band. Each field was exposed for 10 seconds per frame, with three consecutive exposures before moving along the right ascension direction for cyclic shooting. When these four fields were at too high elevation for observation, we observed the known exoplanet field hat-p-29 for calibration; when the elevation of the four fields decreased to a suitable height, we resumed observation.

Table 1 presents the statistics of effective observations from the trial beginning on December 14, 2013, to February 20, 2014. As can be seen from the table, the first four fields—TD1, TD2, TD3, and TD4—are the primary fields. Each of these fields has approximately 1500 frames, with effective observation spans of 24–25 days and effective observation durations of about 140–160 hours, accumulating substantial total data. TD5 serves as a calibration field pointing to hat-p-29. Due to relatively short daily observation times and cloudy weather during some observation nights, the accumulated data for this field is the smallest.

Figure 1 [Figure 1: see original paper] shows the V-band magnitude error diagram, displaying the relationship between V-band magnitude and photometric error after conversion.

3. Data Processing

After obtaining the CCD observation data, we first performed preprocessing including bias subtraction and flat-field correction using IRAF (Image Reduction and Analysis Facility, provided and supported by NOAO). In the second step, we loaded the astronomical coordinate system WCS information using the XAO pipeline combined with the UCAC3 catalog and performed high-order corrections to the WCS via SCAMP. Finally, we used SExtractor to extract fluxes and convert them to magnitudes for all frames.

To eliminate systematic differences between the instrumental magnitudes obtained from each frame, we used the XAO time-domain survey software package. This package simultaneously considers the internal weighting and correlations within the photometric system and incorporates a fast hybrid algorithm [8–10].

Since the original data were taken only in the V band for exoplanet detection, without B, R, or other band data, we could not combine color terms to provide atmospheric extinction correction and extraterrestrial zero-point corrections. Instead, we simply fitted the instrumental magnitude zero-point correction using V-band instrumental magnitudes and Gaia G magnitudes. The conversion relationship between instrumental magnitude V and Gaia G magnitude is shown in Equation (1), and the corresponding relationship between V-band magnitude and photometric error after conversion is shown in Figure 1.

4. Results and Classification

After zero-point correction of the V-band instrumental magnitudes for all targets, we performed classification based on magnitude brightness. We discovered a total of 125 variable sources across the five fields, of which 106 are newly discovered. For all variables, we cross-matched with LAMOST DR5, with results listed in the LAMOST class column. When cross-matching with the GCVS 5.1 catalog and the International Variable Star Index (VSX) from the American Association of Variable Star Observers (AAVSO), we found that five known variables that should have been observed were not detected. Finally, we cross-matched with the newly released Gaia DR2 and found some known variable sources. Below we provide detailed explanations combining the above information on known and newly discovered sources.

Due to the large total number of variable sources, displaying observation charts expanded by field would contain excessive content, so this portion is omitted from the paper. We present the phased light curves for the 106 newly discovered variables in two parts: Figure 2 [Figure 2: see original paper] shows 56 of them, and Figure 3 [Figure 3: see original paper] shows the remaining 50. For clarity, the phase is plotted from zero to 1.5 periods. In each figure, the horizontal axis is the phase, the left vertical axis shows the magnitude variation range, and the right vertical axis indicates the field information—the first keyword starting with TD is the time-domain survey field number, and the second keyword starting with V is the newly discovered variable star ID.

Among these 106 newly discovered variables, 100 are eclipsing binary systems, as shown in Table 2 . From Table 2, we can identify 22 EA-type, 24 EB-type, and 54 EW-type eclipsing binaries.

Our original intention was to discover a batch of RR Lyrae variable stars that could serve as standard candles through data mining. For several variables with similar light curve morphologies, we compared their period-luminosity relations with Gaia parallaxes and found no clear correspondence. Combined with their relatively short periods, we ultimately classified them as Scuti-type pulsating variables. Detailed information is provided in Table 3 .

Table 4 lists another newly discovered variable, V102, which is a target in the TD5 field. Although a periodic relationship was found, the enlarged plot of V102 shows that its phase coherence is not as good as that of other overlapping variables. This may be due to insufficient sampling caused by fewer frames in this field, or it may indeed be a binary system or pulsating variable with period variations. This requires further observation for confirmation, so it is listed separately in Table 4.

Figure 4 [Figure 4: see original paper] shows the V102 variable source, where the light curve does not overlap well with the phase.

Table 5 describes the known variable stars. As can be seen, 19 known variables were observed, plus 5 not detected, making a total of 24. Cross-matching the first 19 known variables with the VSX database shows good agreement in magnitude, variation period, and type. For the five undetected variables, V128 and V129 are in the TD5 field, likely due to insufficient sampling in this field; V126, V127, and V130 are brighter than 11.3 mag, and their non-detection is attributed to CCD pixel saturation during exposure and undersampling.

Among the newly discovered eclipsing binaries, V13 and V38 have no corresponding celestial coordinates in Gaia DR2, so the G magnitude values for these two stars in Table 2 are empty.

5. Discussion

GCVS 5.1 is a widely recognized authoritative reference catalog for variable stars. In this cross-identification, only two of the 125 new variable sources matched with GCVS 5.1. Among 25 variables that should have been discovered, GCVS 5.1 only contained six sources, reflecting the poor completeness of GCVS 5.1. For example, with the continuous increase in equipment and observational capabilities, many new RR Lyrae variables should have been discovered in recent years. After carefully analyzing the GCVS 5.1 catalog, we found that it includes very few sources discovered after 2000. Although the catalog contains more than 50,000 variable sources, fewer than 200 were discovered after 2000, and sources published in 2016–2017 have not been included.

When using the VSX database from AAVSO, which contains more than 600,000 variable stars and is relatively more complete than GCVS 5.1, we still encountered cases where data information was incomplete, with one or several parameters missing from the variable star descriptions.

Before cross-matching with Gaia, we assumed that data from the space telescope Gaia DR2 should be a complete set of optical astronomical targets. However, in practice, we found that new variables V13 and V38 and known variable V113 have no corresponding data in Gaia DR2, leaving the G magnitude entries empty in Tables 2 and 5.

When cross-matching the variables discovered in this search with LAMOST DR5 data, 17 sources were found among the new variables, and nine sources among the known variables. Most are A- and F-type stars, with some G-type stars.

Although the time-domain observations were conducted in relatively dense star fields, the number of variable sources discovered in each field varies greatly. During the search process, we found that for newly discovered variables, the number of effective frames and total observation hours in a single field have a significant impact on the number of new discoveries. Among the new variables, eclipsing binaries account for a very large proportion, with EW-type binaries alone exceeding half. Regarding the distribution of V-band apparent magnitudes, targets brighter than 11.3 mag and fainter than 18 mag are unsuitable for observation due to saturation and photometric errors, respectively. The survey data show that a large proportion of discovered variables are distributed in the 15-17 mag range, because there are more sources in this range and the photometric errors are relatively small. Although the joint observations were conducted several years ago, so many variable sources could still be mined from the data, demonstrating that the aperture, field of view, and observational depth of the Nanshan One-meter Wide-field Telescope still have great potential for variable star searches.

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