Search for White Dwarfs Using LAMOST DR8 Spectra: Postprint

Authors: Cai Jinghao, Han Zhanwen, Xing Lifeng, Ren Juanjuan, Li Jiao

Date: 2024-03-22T00:00:00+00:00

Abstract

White dwarfs are the degenerate cores remaining at the final stage of evolution of low- and intermediate-mass stars, representing the evolutionary endpoint of the vast majority of stars in the universe. The observed properties of large samples of white dwarfs can not only provide tests and constraints for stellar evolution theory, but can also be used to study the formation history and evolution of the Milky Way. By combining the high-precision photometric and annual parallax data from Gaia, we search for white dwarfs in the low-resolution spectral data from the eighth data release (DR8) of LAMOST. Using a template matching method, we find a total of 4,692 white dwarfs and 85 cataclysmic variables in LAMOST DR8, among which 2,876 targets had been previously identified as white dwarfs in earlier work, and 1,854 targets are white dwarfs discovered for the first time in LAMOST. After visual confirmation, we perform detailed classification of the white dwarf spectral types. Through comparison, the completeness of this white dwarf sample is 80%, and the accuracy of classification reaches 99%; the final LAMOST white dwarf sample well reflects the distribution of different types of white dwarfs on the Gaia CMD diagram.

Full Text

Searching for White Dwarfs Based on LAMOST DR8 Spectra

Cai Jing-hao[1;2;3;4], **Han Zhan-wen**[1;2;3;4], **Xing Li-feng**[1;3;4], **Ren Juan-juan**[5], **Li Jiao**[5]

[1]Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming 650011, China
[4]International Centre of Supernovae, Yunnan Key Laboratory, Kunming 650216,

China
[5]National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China

Abstract

White dwarfs are the degenerate cores remaining at the end of evolution for low- and intermediate-mass stars, representing the final evolutionary destination of the vast majority of stars in the universe. The observed properties of large white dwarf samples can not only provide tests and constraints for stellar evolution theory but also be used to study the formation history and evolution of the Milky Way. By combining Gaia' s high-precision photometry and parallax data, we searched for white dwarfs in the low-resolution spectral data from the eighth data release (DR8) of LAMOST. Using template matching methods, we identified a total of 4,692 white dwarfs and 85 cataclysmic variables in LAMOST DR8, among which 2,876 objects had been previously identified as white dwarfs in earlier work, while 1,854 objects represent newly discovered white dwarfs in LAMOST. After visual confirmation, we performed detailed classifications of the white dwarf spectral types. Through comparison, the completeness of our white dwarf sample reaches 80%, with classification accuracy achieving 99%. The final LAMOST white dwarf sample excellently reflects the distribution of different types of white dwarfs on the Gaia CMD diagram.

Keywords: white dwarfs; spectra; LAMOST

1.1 Introduction to White Dwarfs

White dwarfs are the degenerate stellar cores remaining at the end of evolution for low- and intermediate-mass stars. Stars with initial masses $M < 7.0\ M$ will eventually evolve into white dwarfs. Such stars, during the double-shell burning phase at the tip of the asymptotic giant branch (AGB) at the end of their evolution, eject most of their hydrogen-rich envelopes through stellar winds, leaving behind an electron-degenerate C-O core. For stars with initial masses $7.0\ M < M < 11.0\ M$, depending on metallicity and mass loss rates, different evolutionary products can be produced, including O-Ne white dwarfs, electron-capture supernovae, and Fe-core collapse supernovae [1].

Additionally, white dwarfs may also be products of multiple star system evolution. Theoretically, white dwarfs with masses less than (0.3-0.45) M can only be explained as products of close binary star evolution [2], because the main-sequence lifetime of a single progenitor star for such low-mass white dwarfs would exceed the age of the universe. Extremely low-mass white dwarfs (ELMWDs), defined as white dwarfs with masses less than (0.2–0.3) M [3, 4], are theoretically believed to form through binary systems that lose their outer envelopes during the common envelope or stable Roche lobe overflow phase, exposing the stellar core [5]. When the core is in a degenerate state and loses its envelope mass without triggering He fusion, an ELMWD is produced. ELMWDs have surface gravities similar to subdwarfs but typically lower effective temperatures ($T_{eff} \leq 20{,}000$ K). Hot subdwarfs, by contrast, result from envelope loss after He ignition in the core, placing them on the zero-age horizontal branch (ZAHB). Additionally, it is estimated that 25%-30% of white dwarfs are produced through merger events.

White dwarfs have luminosities comparable to or even fainter than dwarf stars, but their higher temperatures give them bluer colors, placing them in the lower left region of the Hertzsprung-Russell diagram relative to main-sequence stars. The luminosity range of white dwarfs spans more than seven orders of magnitude, with the faintest known white dwarfs having L $10^{-4.7}$ L , while white dwarfs that have just entered their cooling evolutionary tracks can reach luminosities of L 10^{2-10}3 L [6]. With nuclear fuel exhausted, white dwarfs radiate energy solely through heat stored in their non-degenerate ions and weak gravitational contraction, a process known as white dwarf cooling. The average mass of white dwarfs is approximately 0.6 M , with radii close to Earth’ s radius. Since electron degeneracy pressure is independent of temperature, white dwarfs maintain essentially constant radii during evolution. White dwarf cooling timescales are extremely long, with a typical white dwarf requiring approximately 10 Gyr to cool to 3,000 K [6]. Considering the nuclear burning history of white dwarf progenitors and gravitational settling, typical white dwarfs have a thin He-rich shell surrounding their C-O core, which is itself surrounded by a thin H-rich shell. Although these shells are very thin, they are extremely opaque to radiation and control the outward transport of energy from the white dwarf, thus playing a crucial role in the cooling process. The exact masses and thicknesses of the H and He shells have become a hot research topic in this field.

The white dwarf cooling process constitutes not only a fundamental physical problem, providing independent verification for dense plasma physics theory, but also enables white dwarf cooling evolutionary tracks to serve as independent age and distance indicators for various stellar populations. Specifically, the theoretical luminosity function (LF) derived from differences in cooling degrees among white dwarfs of different masses can use its decline at the low-luminosity end as an independent indicator to constrain the ages and histories of various Galactic populations (e.g., the Galactic disk, globular clusters, and open clusters). Using multi-color photometry and spectroscopy, white dwarf effective temperatures and surface gravities can be precisely determined, and white dwarf masses can be obtained according to theoretical mass-radius relations. These fundamental parameters provide constraints and corrections for several important issues in stellar evolution theory, such as mass loss rates during the AGB phase, internal rotation profiles and angular momentum loss of stars, and fundamental nuclear reaction rates. The white dwarf mass distribution can reflect the initial mass function and initial-final mass relation at different metallicities. Additionally, the mass function can be used to study the role of binary evolution in the formation of some white dwarfs. Since over 97% of stars in the Milky Way are expected to eventually evolve into white dwarfs, the properties of the white dwarf population provide valuable information for studying the star formation history and evolution of our Galaxy. The white dwarf luminosity function can measure the death rate of local low- and intermediate-mass stars, allowing the star formation rate and star formation history (SFH) to be inverted from the luminosity function, and has been used in existing studies to determine the age of the thin disk. Since white dwarf progenitors eject large amounts of C, N, and O elements during the AGB phase, white dwarfs play an important role in Galactic chemical evolution. Studying the properties of white dwarf populations requires large, well-defined white dwarf samples.

1.2 White Dwarf Classification

Based on the main components of their surface envelope atmospheres, white dwarfs are divided into two distinct primary categories. Approximately 80% of white dwarfs show only H Balmer lines, with surface atmospheres composed primarily of H, and are classified as DA-type white dwarfs. These white dwarfs have effective temperatures above 5,000 K. The remaining approximately 20% have surface atmospheric compositions dominated by He, lacking H in their atmospheres, and are classified as non-DA white dwarfs. Non-DA white dwarfs contain several subclasses: the hottest are called DO-type white dwarfs, with 4.5×10^4 K < T_{eff} < 2×10^5 K, whose spectra show singly ionized He (He II) lines, while H Balmer lines and neutral He (He I) lines are also visible in the spectra; cooler ones are called DB-type white dwarfs, typically with 1.1×10^4 K < T_{eff} < 3×10^4 K, whose spectra contain only He I lines; DZ-type white dwarfs show primarily metal lines (dominated by Ca II K and Ca II H lines) in their spectra, with effective temperatures usually below 1.1×10^4 K; DQ-type white dwarfs show C2 Swan molecular bands or neutral C (C I) lines in their spectra, also typically with effective temperatures below 1.1×10^4 K. Additionally, for a small number of ultra-cool H-atmosphere white dwarfs (T_{eff} < 5,000 K) and ultra-cool He-atmosphere white dwarfs (T_{eff} < 1.1×10^4 K) that show featureless smooth continua, they are classified as DC-type white dwarfs. Figure 1 [Figure 1: see original paper] shows typical spectra of different types of white dwarfs.

Observational evidence indicates that the spectral type of a single white dwarf may evolve with the cooling process, meaning the dominant elements in the spectrum change. This suggests that white dwarf surface atmospheric composition may be affected by convection, mass loss, accretion, radiative levitation, and gravitational settling. As cooling proceeds, DO-type white dwarf spectra transition from being dominated by He II lines to He I lines, and the white dwarf type changes from DO to DB. However, only a small number of H-deficient white dwarfs have been observed in the transition temperature range (3×10^4 < T_{eff} < 4.5×10^4 K) between DO and DB types, a phenomenon known as the DB gap. This interval contains some mixed-atmosphere white dwarfs, "hot DQ" white dwarfs dominated by C II lines in their spectra, and a small number of O-rich atmosphere white dwarfs (DS type). The known ratio of DA-type to non-DA-type white dwarfs is a function of effective temperature [6], suggesting that convection or gravitational settling may cause small amounts of H in some originally hot H-deficient white dwarfs (PG 1159 stars or DO types) to gradually reach the atmospheric surface and float on top of the He envelope, forming an H-rich atmosphere [7, 8]. At the lower edge of the DB gap, the development of larger mass convective He envelopes may dilute the thin H radiative layer, transforming the H-dominated atmosphere back into a He-dominated atmosphere. Over half of DB-type white dwarfs are DBA types showing weak H lines, indicating that DA-type white dwarfs with thin H envelopes may begin transitioning to DB-type white dwarfs due to convection at lower temperatures.

Approximately 3% of white dwarfs show metal pollution (primarily Ca II K and Ca II H lines), which can only be explained by accretion of interstellar medium or circumstellar material (such as asteroids) onto cool white dwarfs [9]. Except for very hot objects ($T_{eff} > 5 \times 10^4$ K) where radiative levitation still plays an important role in the appearance of metal lines [10]. In rare cases, the convective zone beneath the He envelope is deep enough to dredge up C to the surface, causing these white dwarfs to show C2 molecular bands or C atomic lines in their spectra, forming DQ-type white dwarfs. Even rarer are white dwarfs with O-rich atmospheres containing small amounts of Ne and Mg elements, with spectra dominated by O lines and lacking H and He lines, classified as DS-type white dwarfs.

1.3 White Dwarf Observations and Searches

Due to the lack of large-aperture, high-precision survey telescopes in early times, the number of white dwarfs discovered and spectroscopically confirmed was very limited. White dwarf search efforts included observing blue faint stars in proper motion catalogs and searching for ultraviolet-excess objects. McCook and Sion [11] published the first spectroscopically confirmed white dwarf catalog in 1977. Constrained by equipment and technology at the time, the discovered white dwarfs were biased toward hot stars, fast-moving stars, and stars with larger radii and smaller masses [12].

In the past two decades, thanks to large-area, high-precision survey projects such as SDSS (Sloan Digital Sky Survey), GALEX (Galaxy Evolution Explorer), Gaia (Global astrometric interferometer for astrophysics), and LAMOST (Large Sky Area Multi-Object Fiber Spectroscopy Telescope), efficient searches for large samples of white dwarfs have become possible.

The largest spectroscopically confirmed white dwarf catalog published to date comes from SDSS. The SDSS project uses a 2.5 m telescope located at Apache Point Observatory in New Mexico, USA, aiming to obtain photometric and spectroscopic data for vast numbers of celestial objects to deepen understanding of galaxy formation and evolution, large-scale structure of the universe, and other fields. SDSS spectra are obtained using different spectrographs: the SDSS-I/II spectrograph covers wavelengths of 3,800–9,200 Å with resolution of 1,850–2,200; the BOSS spectrograph covers 3,650–10,400 Å with resolution of 1,500 at

3,800 Å and 2,200 at 9,000 Å. The most recent SDSS white dwarf catalog was established by Kepler et al. [13]. Based on SDSS DR14 data, they performed preliminary screening of white dwarf candidates according to the color range for white dwarfs selected by Eisenstein et al. [14], proper motions greater than 20 mas yr^{-1} at 3σ, and hot stars classified by the SDSS Pipeline software. They then examined all candidate spectra to confirm line features, ultimately obtaining a master catalog of 37,053 sources, of which 20,088 are white dwarfs. In addition to white dwarfs, the catalog contains hot subdwarfs (sdOs, sdOBs, sdBs), cataclysmic variables (CVs), narrow hydrogen-line objects (sdAs), and carbon stars (dCs). Based on SDSS DR16, they also reported 2,410 newly identified white dwarf-containing objects and spectral classifications [15]. Kepler et al. [13, 15] used Koester' s [16] atmospheric models to fit all white dwarfs and hot subdwarfs with S/N > 10 in their catalog, then determined T_{eff} and log g values, and finally estimated masses for DA, DB, DC, and DZ-type white dwarfs.

The LAMOST survey has become another important source for white dwarf searches due to its efficient acquisition of massive spectroscopic data. Several white dwarf search efforts based on LAMOST low-resolution spectral data have been published. Zhang et al. [17] discovered 230 DA-type white dwarfs from the pilot survey by fitting Sersic profiles to Balmer lines combined with visual confirmation. Using LAMOST Pipeline spectral classifications, fitting Sersic profiles to Balmer lines, performing color-color cuts, and final visual confirmation, Guo et al. [18] discovered 1,056 DA, 34 DB, and 276 white dwarf-main-sequence binaries in DR2. Kong et al. [19] identified 287 DB-type white dwarfs in DR5 using machine learning methods including LASSO (Least Absolute Shrinkage and Selection Operator) and SVM (Support Vector Machine). The same method is being applied to subsequent LAMOST data releases. Additionally, searches for white dwarf-main-sequence binaries in LAMOST have continued. Ren et al. [21] developed an algorithm based on wavelet transforms that can detect Balmer lines at the blue end and molecular absorption bands at the red end, identifying 876 white dwarf-main-sequence binaries in DR5. With the continuous release of LAMOST spectral data, white dwarf searches and identifications warrant further development.

2 Data Sources

We used low-resolution spectral data from the LAMOST pilot survey and the first eight years of formal surveys, combined with Gaia EDR3 astrometric and photometric data, to search for white dwarfs in the LAMOST spectral database and expand the LAMOST white dwarf sample.

2.1 Gaia Data

Gaia is the European Space Agency' s successor mission to HIPPARCOS, designed to precisely measure the three-dimensional spatial and velocity distributions of over one billion stars and determine their astrophysical properties, such as surface gravity and effective temperature, to create precise three-dimensional maps of stars in the Milky Way and understand the structure, formation, and evolution of our Galaxy.

Gaia' s imaging relies on two telescopes with apertures of 1.45 m × 0.5 m, equipped with three terminal instruments: an astrometric instrument, a photometer, and a radial velocity spectrometer, used to measure stellar positions, proper motions, parallaxes, brightness, and spectra. The parallax measurement precision reaches microarcsecond levels for the first time, with a G-band limiting magnitude of 20 mag. The Gaia satellite was launched in December 2013 and operates at the Sun-Earth Lagrange L2 point. After half a year of commissioning and performance verification, formal scientific operations began in summer 2014. The first data release (DR1) and second data release (DR2) were released in 2016 and 2018, respectively. This work uses the third early data release (EDR3) published in 2020, which is part of the complete DR3 dataset based on 34 months of data collected between July 25, 2014, and May 28, 2017, covering over 1.8 billion celestial targets. EDR3 includes updated source lists, right ascension, declination, parallax, proper motions, G, GBp, and GRp broadband photometric magnitudes, and an updated radial velocity list from DR2. Among these, 882 million sources have six astrometric parameters (right ascension, declination, parallax, right ascension proper motion, declination proper motion, and pseudo-color), 585 million sources have five astrometric parameters (without pseudo-color), and 344 million sources have only mean positions (mostly faint objects).

Compared with DR2, EDR3' s parallax measurement precision has improved by an average of 20%-30%, and proper motion measurement precision has doubled. Additionally, photometric measurements are more uniform not only across the sky but also in the distribution of target magnitudes and colors. The catalog also contains new diagnostic parameters to facilitate more reliable quality cuts.

2.2 LAMOST Data

The "Large Sky Area Multi-Object Fiber Spectroscopy Telescope" (LAMOST), also known as the Guo Shoujing Telescope, is a meridian-reflecting Schmidt telescope with an effective aperture of 3.6–4.9 m, located at the Xinglong Observatory of the National Astronomical Observatories, Chinese Academy of Sciences, in Xinglong County, Chengde City, Hebei Province. The main structure consists of a reflecting Schmidt corrector mirror (Ma) in the north, a spherical primary mirror (Mb) in the south, and a focal plane in between. During observations, the spherical primary mirror and focal plane remain fixed on the ground, while the corrector mirror tracks targets as they pass near the meridian. Since the corrector mirror innovatively employs active optics technology, breaking through the technical bottleneck that large aperture and wide field of view cannot be simultaneously achieved, LAMOST is currently the largest wide-field survey telescope in operation. The focal plane has a diameter of 1.75 m and uses parallel controllable fiber positioning technology to simultaneously control the real-time positions of 4,000 fibers. These technological implementations give LAMOST a large field of view of 20 square degrees, enabling simultaneous spectroscopic observations of 4,000 targets in both red and blue bands in a single exposure, making it the telescope with the highest spectral acquisition rate in the world. The LAMOST low-resolution survey has 16 spectrographs, each connected to 250 fibers and two CCD cameras. The red band covers wavelengths of 5,700–9,000 Å, the blue band covers 3,700–5,900 Å, with a resolution of approximately 1,800. The average exposure time per target is 1.5 hours, reaching a limiting magnitude of 17.8 mag. The two-dimensional spectral images produced after the spectrograph disperses starlight through gratings undergo processing by the LAMOST 2D Pipeline software (extraction, flat-fielding, calibration, sky subtraction, merging of red and blue data) to obtain one-dimensional spectra, which are then processed by the LAMOST 1D Pipeline software (template matching, analysis, spectral classification, redshift measurement, parameter measurement, packaging) to produce catalog data products. The main scientific objectives of the LAMOST low-resolution spectral survey include the structure and evolution of the Milky Way, stellar population census, searches for special objects (Li-rich giants, metal-poor stars, hypervelocity stars, white dwarfs, etc.), exoplanet searches, star formation, formation and evolution of nearby galaxies, and quasar searches.

3 Data Processing

We cross-matched LAMOST DR7 and the eighth year of formal survey low-resolution spectral data with the Gaia EDR3 catalog. LAMOST uses fibers with a diameter of 3 , and the fiber pointing error averages no more than 1.5 . Considering these factors, we adopted a cross-matching radius of 3 . This yielded 10.45 million LAMOST spectra with Gaia photometric data, for which the absolute magnitudes of these spectral targets can be obtained from:

$$G_{\text{abs}} = m_G - 5\log_{10}\left(\frac{1}{p}\right) + 5$$

where G_{abs} is the absolute magnitude in the Gaia G band, m_G is the mean photometric magnitude in the Gaia G band, and p is the annual parallax from Gaia in units of milliarcseconds.

After retrieving $G_{\text{BP}} - G_{\text{RP}}$ colors for all LAMOST spectra, we plotted the distribution of these objects in the Gaia CMD diagram, as shown in Figure 2 [Figure 2: see original paper]. To determine the distribution of white dwarfs and contaminating objects in the CMD diagram, we cross-matched the catalog of white dwarfs and contaminating objects identified from SDSS DR14 by Kepler et al. [13] with the Gaia EDR3 catalog. After obtaining Gaia photometric data for SDSS objects, we plotted them together with all LAMOST objects in the same CMD diagram, as shown in Figure 3 [Figure 3: see original paper]. In Figure 3, the large region where gray points representing LAMOST objects are concentrated corresponds to the edge of the main-sequence region, while blue points representing white dwarfs are mainly concentrated in the region separated from the main sequence at 6.5 < G_{abs} < 15 mag and -0.6 < G_{BP} - G_{RP} < 1.5 mag. As seen in Figure 3, the white dwarf-dominated region partially overlaps with other contaminating objects such as hot subdwarfs, post-AGB stars, and sdA stars. Therefore, selecting white dwarfs based on the Gaia CMD diagram inevitably introduces additional objects. To make our selection more efficient—that is, to select white dwarfs from LAMOST as completely as possible while excluding large numbers of main-sequence stars—we defined a set of cuts along the edge of the main sequence in the diagram:

$$G_{\mathrm{abs}} > -1.387$$

$$G_{\mathrm{abs}} > 7.5 \times ((G_{\mathrm{BP}} - G_{\mathrm{RP}}) + 0.1)^3 + 20 \times ((G_{\mathrm{BP}} - G_{\mathrm{RP}}) + 0.1)^2 + 20.8 \times ((G_{\mathrm{BP}} - G_{\mathrm{RP}}) + 0.1) + 0.9$$

$$G_{\mathrm{BP}} - G_{\mathrm{RP}} < 4.5$$

$$G_{\mathrm{abs}} > 1.6 \times (G_{\mathrm{BP}} - G_{\mathrm{RP}}) + 7.6075$$

Note: Black points represent selected white dwarf candidates.

The selected white dwarf candidates, shown as black points in Figure 2, contain 14,851 spectra. For white dwarf identification, we used template matching supplemented by visual inspection. We selected known white dwarf spectra of various types (including DA, DB, DO, DC, DZ, DQ, DS, DA+M, CV) with S/N > 50 from SDSS DR14 and degraded their resolution to match LAMOST spectral resolution to serve as templates. For white dwarf candidates with S/N > 10, we matched their spectra with template spectra in wavelength ranges where white dwarf spectral features are concentrated (mainly in the blue region). Finally, we performed visual confirmation and classification of spectra matched as white dwarfs. For candidates with S/N < 10, we conducted direct visual inspection; if the spectrum showed white dwarf characteristics within visual range, we classified it as a high-confidence white dwarf candidate.

Before visual confirmation, we performed one-to-one correspondence between SDSS DR14 white dwarf spectra and homologous spectra in LAMOST DR8, and visually learned the characteristics of different white dwarf types in both SDSS and LAMOST.

Observationally, white dwarf classification is based on characteristic spectral lines. The characteristic lines of different white dwarf types reflect physical parameters including surface atmospheric structure and chemical composition, effective temperature, surface gravity, and magnetic field strength. After becoming familiar with various white dwarf spectra, we adopted the following criteria for visual confirmation and classification of all white dwarf candidates in LAMOST DR8:

1. H I Balmer lines are typically broad, accompanied by severe Balmer decrement (DA, DAB, DBA, DZA, and subdwarfs)

2. He I line at 4,471 Å (DB, subdwarfs)
3. He II line at 4,686 Å (DO, PG 1159, sdO)
4. C2 Swan molecular bands or atomic C I lines (DQ)
5. Ca II H&K lines (DZ, DAZ, DBZ)
6. C II line at 4,367 Å (hot DQ)
7. Zeeman splitting (magnetic white dwarfs, marked with H)
8. Featureless spectrum with significant proper motion (DC)
9. Increased flux at red end (binaries, likely M dwarfs)
10. O I lines at 6,158 Å, 7,774 Å, 8,448 Å (DS, O-dominated)
11. H and He emission lines (cataclysmic variables or M dwarfs)

Additionally, some extra markers were added to the above main white dwarf types to assist or refine classification:

1. E: presence of emission lines
2. ?: indicates uncertain classification, can also use colon (:)
3. X: special or unclassifiable spectrum
4. V: optional symbol indicating variable star
5. d: presence of circumstellar dust

White dwarf spectra are generally simpler than those of other stellar types, containing only a few elemental lines corresponding to specific white dwarf types (H, He, Ca, C, O elements), reflecting the simple atmospheric composition of white dwarfs, with at most a few types of characteristic lines mixed in the spectrum. Our classification principle was: if characteristic lines of any white dwarf type dominate the spectrum, that type is assigned as the primary type; if other types of characteristic lines appear but are weaker relative to the primary lines, the corresponding type marker is added after the primary type as a subtype.

4 Results and Discussion

After template matching and visual confirmation of all spectra, we discovered 4,777 independent targets corresponding to 6,032 spectra in LAMOST DR8 data, of which 4,692 targets are white dwarfs and the remaining 85 targets are cataclysmic variable systems. Comparing with previously published LAMOST white dwarf catalogs, 2,876 targets in our catalog had been previously identified as white dwarfs, while 1,854 targets are newly identified white dwarfs in LAMOST.

After visually inspecting all 14,851 spectra, the final classification results are shown in Table 1 . During classification, we marked all visually identifiable spectral features, and for weaker features in the spectrum, we also added them as subtypes after the primary white dwarf type. The classifications in the table represent the sum of all targets with the same primary type.

Comparing the white dwarf catalog identified in LAMOST DR8 with the SDSS DR14 white dwarf catalog, we found that DC-type white dwarfs account for up to 9% of all white dwarfs in SDSS, while in our LAMOST DR8 data, DC-type white dwarfs comprise only 2%. We analyze that this may be because DC-type white dwarfs have lower luminosities, and LAMOST' s limiting magnitude is shallower than SDSS, so LAMOST can only observe a very small number of nearby cool white dwarfs. Furthermore, the vast majority of DC-type white dwarfs in SDSS DR14 have S/N < 10, and such distant cool white dwarfs have extremely low spectral S/N in LAMOST, making it impossible for us to resolve spectral profiles, and thus we cannot confirm those cool white dwarfs with S/N < 10.

Plotting the white dwarfs identified in LAMOST DR8 together with recently released SDSS DR16 white dwarfs in the Gaia CMD diagram, we studied the distribution of different white dwarf types, as shown in Figure 4 [Figure 4: see original paper]. As shown in Figure 4, DA-type white dwarfs are distributed across the region marked by black dots, with the widest distribution range, while other white dwarf types show clustered distributions only in specific regions. DO-type white dwarfs are distributed in the upper left of the white dwarf dense region, i.e., the starting point of the white dwarf cooling sequence, while DB-type white dwarfs are distributed in regions with redder colors and larger absolute magnitude values. There is a discontinuous distribution region of H-deficient white dwarfs between DO-type and DB-type white dwarfs, the so-called DB gap. The distribution tracks of DQ, DZ, and DC-type white dwarfs have some overlap, but the distribution of DQ white dwarfs shows obvious additional "structure." For cool white dwarfs, our method can only identify objects in LAMOST data down to G_{BP} - G_{RP} < 0.9 mag, while SDSS can identify white dwarfs at the low-temperature end down to G_{BP} - G_{RP} 1.5 mag. It can be seen that the distribution of LAMOST DR8 white dwarfs identified by us is basically consistent with SDSS white dwarfs. After cross-matching our white dwarf catalog with the SDSS DR16 white dwarf catalog, 20 out of 2,571 common targets have inconsistent classification results for primary white dwarf type and white dwarf-main-sequence binary classification, giving the catalog a white dwarf classification accuracy of 99%. Table 2 shows partial data from the LAMOST DR8 white dwarf catalog.

To determine the completeness of this white dwarf sample, we cross-matched it with the Gaia EDR3 white dwarf catalog [22] containing 359,073 high-confidence white dwarf candidates (P_{WD} > 0.75), retrieving our identified white dwarfs among the common sources. The resulting completeness of the white dwarf sample is 80%.

The white dwarf catalog data from this paper (DOI: 10.57760/sciencedb.08123) can be accessed and obtained from the Chinese Academy of Sciences Science Data Bank (https://www.scidb.cn/s/3MFFzy) for open use by astronomers.

References

[1] Woosley S E, Heger A. ApJ, 2015, 810: 34
[2] Kilic M, Stanek K Z, Pinsonneault M H. ApJ, 2007, 671: 761

[3] Sun M, Arras P. ApJ, 2018, 858: 14
[4] Calcaferro L M, Althaus L G, Córsico A H. A&A, 2018, 614: A49
[5] Li Z, Chen X, Chen H-L, Han Z. ApJ, 2019, 871: 148
[6] Fontaine G, Brassard P, Bergeron P. PASP, 2001, 113: 409
[7] Fontaine G, Wesemael F. IAU, 1987, 95: 319
[8] Manseau P M, Bergeron P, Green E M. ApJ, 2016, 833: 127
[9] Koester D, Gänsicke B T, Farihi J. A&A, 2014, 566: A34
[10] Barstow M A, Barstow J K, Casewell S L, et al. MNRAS, 2014, 440: 1607
[11] McCook G P, Sion E M. Villanova University Observatory Contributions. Villanova: Villanova Press, 1977
[12] Shipman H L. ApJ, 1979, 228: 240
[13] Kepler S O, Pelisoli I, Koester D, et al. MNRAS, 2019, 486: 2169
[14] Eisenstein D J, Liebert J, Harris H C, et al. ApJS, 2006, 167: 40
[15] Kepler S O, Koester D, Pelisoli I, et al. MNRAS, 2021, 507: 4646
[16] Koester D. Mem Soc Astron Italiana, 2010, 81: 921
[17] Zhang Y Y, Deng L C, Liu C, et al. AJ, 2013, 146: 34
[18] Guo J, Zhao J, Tziamtzis A, et al. MNRAS, 2015, 454: 2787
[19] Kong X, Luo A L, Li X R. Research in Astronomy and Astrophysics, 2019, 19(6): 088
[20] Guo J, Zhao J, Zhang H, et al. MNRAS, 2022, 509: 2674
[21] Ren J J, Rebassa-Mansergas A, Parsons S G, et al. MNRAS, 2018, 477(4): 4641
[22] Gentile Fusillo N P, Tremblay P E, Cukanovaite E, et al. MNRAS, 2021, 508(3): 3877

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

Source: ChinaXiv —Machine translation. Verify with original.