Identification of Carbon Stars from LAMOST DR7

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3 Identification and Spectral Classification

4 Discussion and Conclusion

1 Background

- Carbon stars are excellent kinematic tracers of galaxies and play important roles in understanding the evolution of the Galaxy.
- Carbon stars are rare and peculiar objects first discovered by Secchi (1869), and characterized by strong carbon molecular bands, such as CH, CN, and C_2, in their optical spectra.
- Carbon stars usually have similar temperature and luminosity with late G, K, and M stars, while showing higher carbon abundance than oxygen (C/O> 1; Keenan 1993).
- According to their different spectral features, carbon stars can be classified into different subclasses (Keenan 1993; Barnbaum et al. 1996), including C–H, C–R, C–N, C–J, and Ba stars.
- They can also be divided into giant carbon and dC (dwarf Carbon) stars depending on their brightness.

1 Background

- Almost all Ba and C–H stars are binaries (McClure et al. 1980; McClure 1983; Jorissen et al. 2016; Escorza & De Rosa 2023; Goswami & Goswami 2023).

- Aikman & McClure (1984) carried out a series of radial velocity monitoring for C–N stars and found signs of binary companions for C–N stars.
- However, McClure (1997) did not find any evidence of binary for 22 C–R stars after 16 yr of radial velocity monitoring.

2 Data

- LAMOST can simultaneously obtain the spectra of 4000 targets in a single exposure, and its resolution is ~1800 for the low-resolution mode.

- The DR7 data set contains 14,487,406 spectra, including 10,599,979 low-resolution spectra, and 1,008,710 non-time-domain and 2,878,717 time-domain medium-resolution spectra.
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- In the LAMOST DR7 Low-Resolution Spectroscopic (LRS) General Catalog,5 there are 4402 spectra of 3565 stars labeled as carbon for the "subclass" parameter (stellar spectral type).
- However, the contamination rate is not presented, and no classification of the carbon stars is given.
- In this work, we systematically search for different types of carbon stars from more than 10 million low-resolution spectra.

2.1 Line Indices

- They use the multiple line index to select carbon stars, as the spectra of carbon stars are characterized by strong absorption bands of carbon-containing molecules.
- The line index is defined by the following equation according to the equivalent width (Worthey et al. 1994; Liu et al. 2015):

$$\mathrm{EW} = \int \left[1 - \frac{f_{\mathrm{line}}(\lambda)}{f_{\mathrm{cont}}(\lambda)}\right] d\lambda, \qquad (1)$$

where $f_{cont}(\lambda)$ and $f_{line}(\lambda)$ are the fluxes of the continuum and the spectral line.

The line index under this definition is in Å.

We measure five line indices including C_2(λ 4737 Å, λ 5165 Å, and λ 5635 Å) and CN (λ 7065 Å, and λ 7820 Å). The definition of line indices is listed in Table 1.

Table 1
Line Indices Definition in This Work

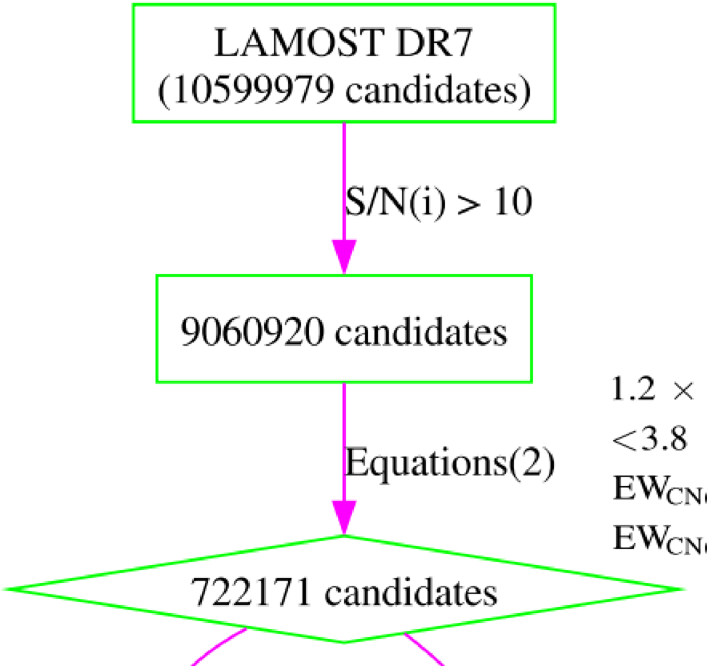
Name (1)	Index Bandpass (Å) (2)	Pseudocontinua (Å) (3)
C_2(4737 Å)	4620–4742	4580–4620 4742–4812
C_2(5165 Å)	4980–5170	4930–4980 5170–5235
C_2(5635 Å)	5350–5640	5300–5350 5640–5700
CN(7065 Å)	7065–7190	7025–7065 7190–7230
CN(7820 Å)	7820–8000	7790–7820 8000–8040

3 Identification and Spectral Classification

➢3.1 The Identification Steps of Carbon Stars

- The high S/N spectra are helpful to us to identify and classify carbon stars more accurately.

  Different types of stars are mixed, and it is very difficult to identify the carbon stars in the highly contaminated region.



$$1.2 \times EW_{CN(\lambda\,7065\,Å)} - 1.29 < EW_{CN(\lambda\,7820\,Å)}$$
$$< 3.8 \times EW_{CN(\lambda\,7065\,Å)} + 3.0,$$
$$EW_{CN(\lambda\,7065\,Å)} > 0.7,$$
$$EW_{CN(\lambda\,7820\,Å)} > 1.0.$$

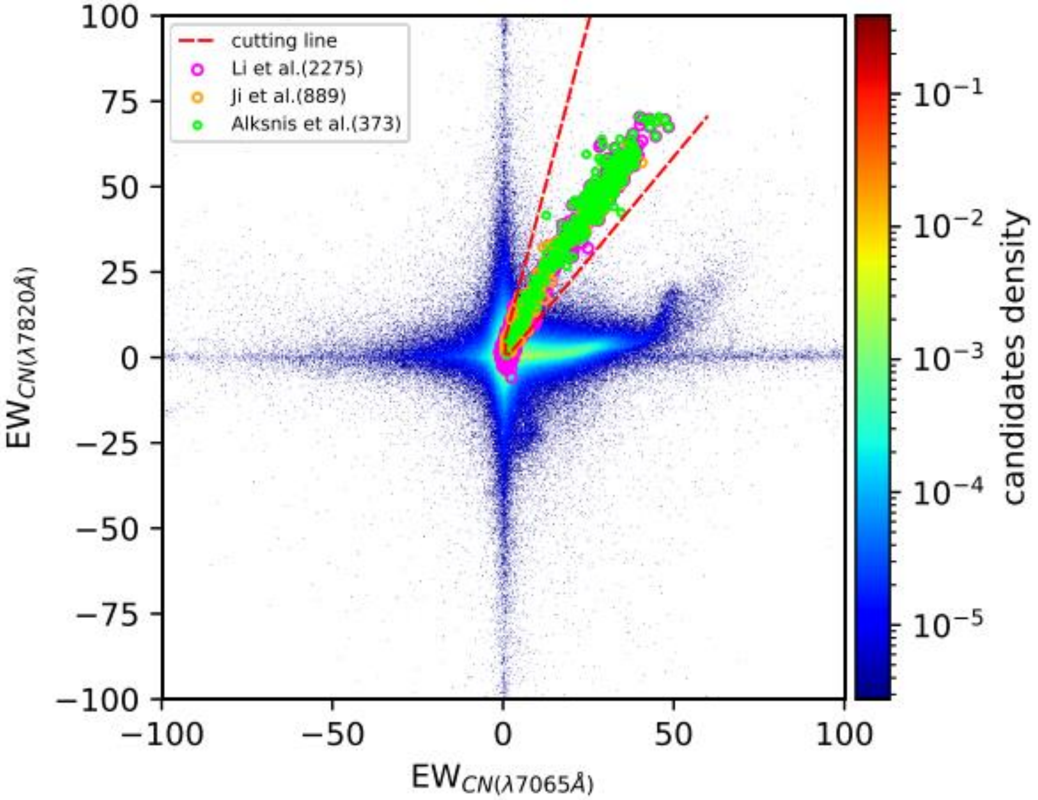
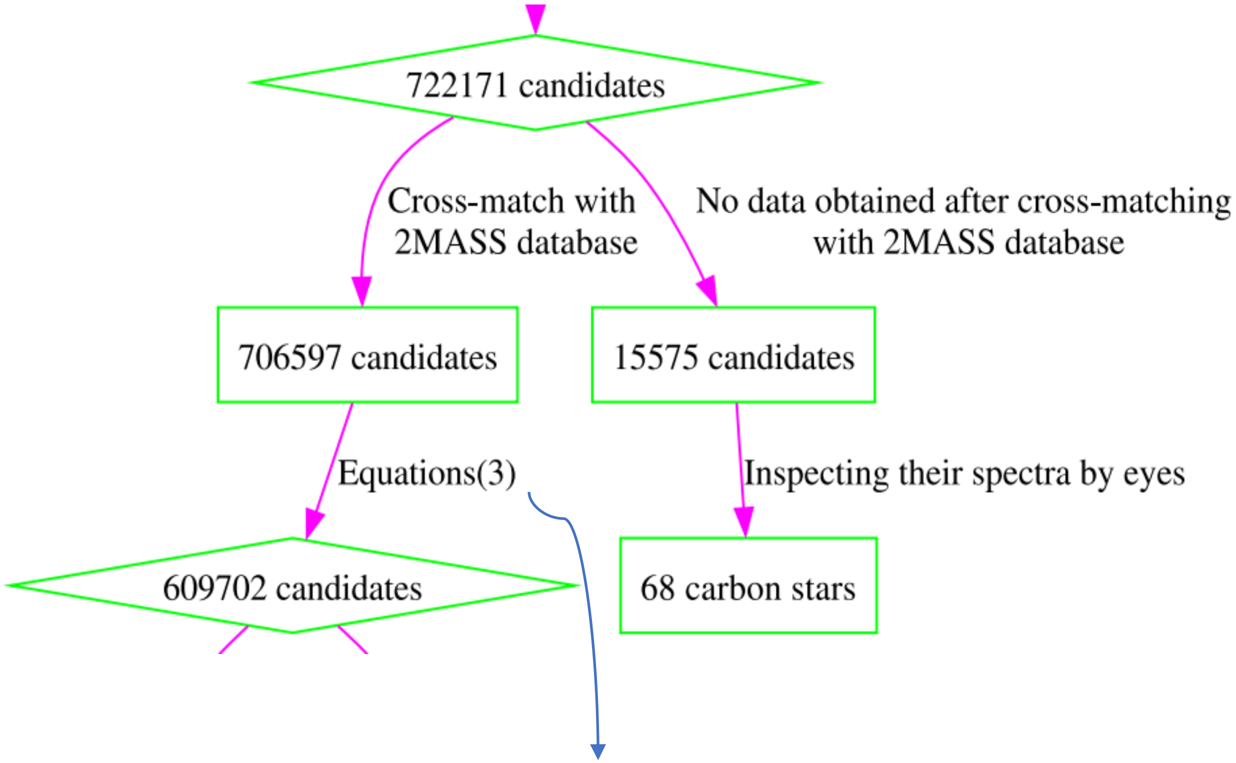


Figure 1. Distribution of the 9,060,920 spectra.

➢3.1 The Identification Steps of Carbon Stars

- They further remove pollution based on the infrared color– color diagram.



$$J - H > 0.5 \times (J - K_s) - 0.1,$$
$$J - H < 0.8 \times (J - K_s) + 0.3,$$
$$J - H > -2.0 \times (J - K_s) + 1.0.$$

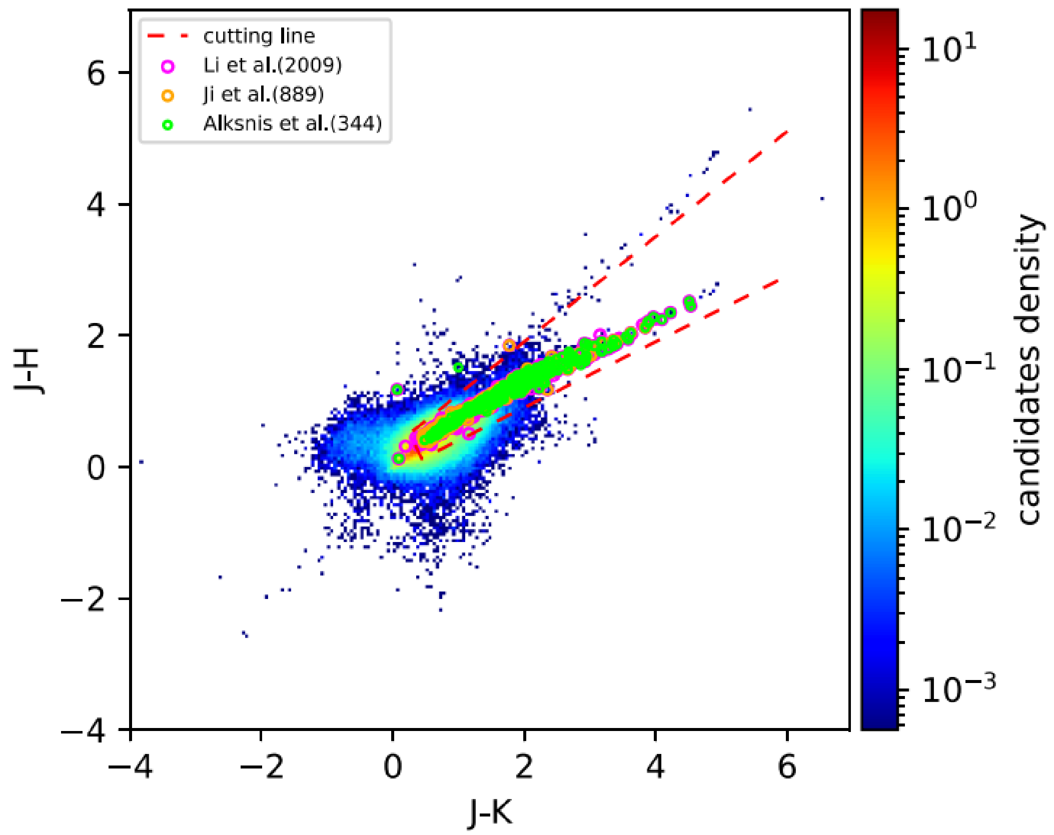
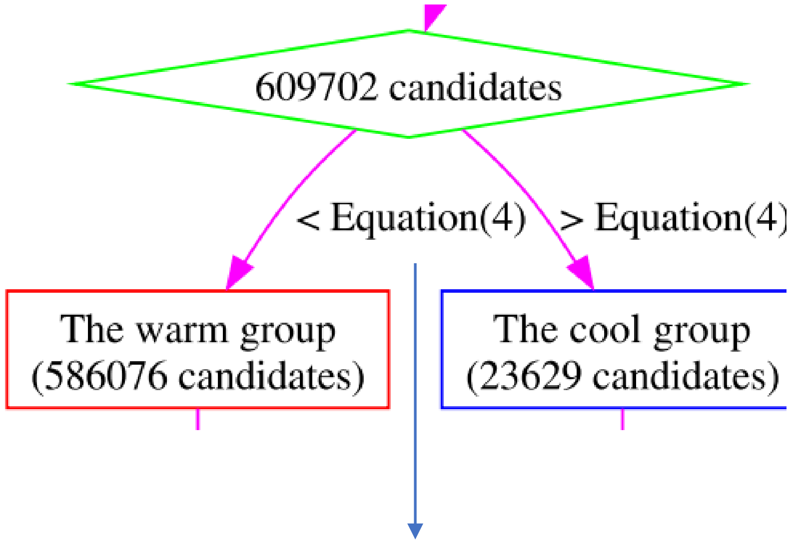


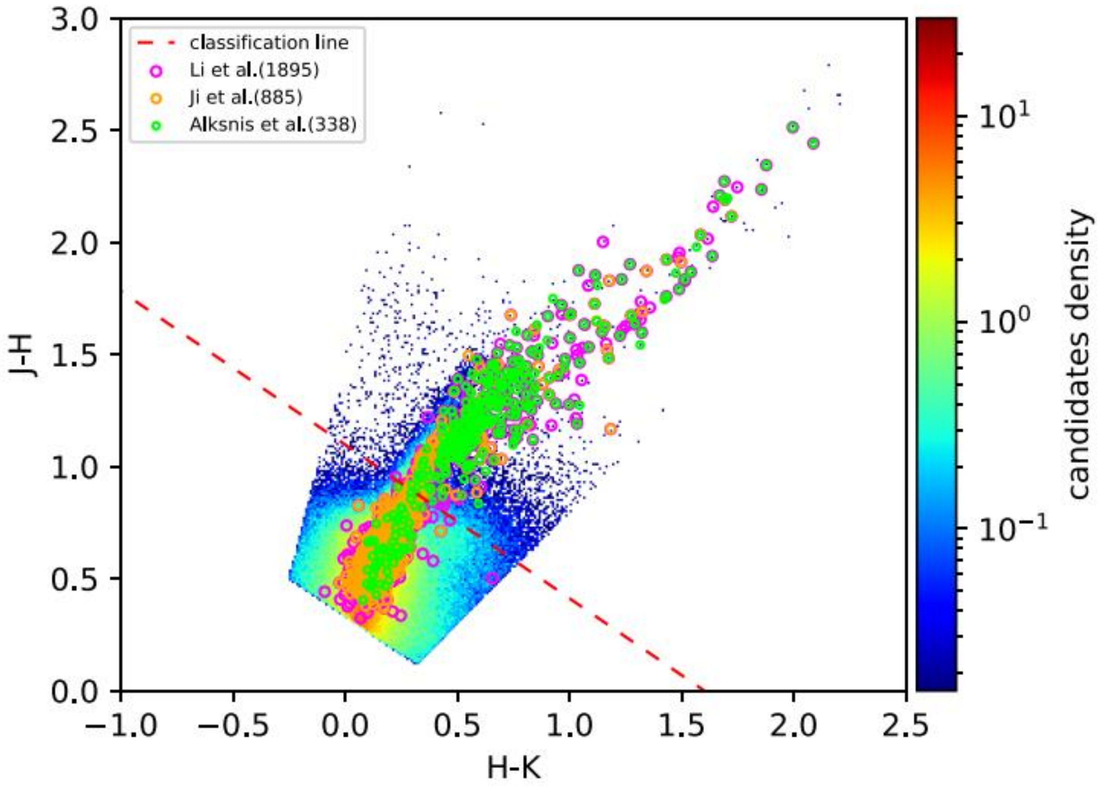
Figure 2. Distribution of the 706,597 candidates and the known carbon stars in the J– H vs. J– Ks color–color diagram. The solid dots indicate the density of the candidates.

➢3.1 The Identification Steps of Carbon Stars



$$J - H = -0.6851 \times (H - K_s) + 1.0974.$$

The lower left of the dashed line is the Warm Group, the upper right is the Cool Group.



The red dashed line: Si et al. (2015)

Figure 3. Distribution of the 609,702 candidates and the known carbon stars in the J− H vs. H− K_s color–color diagram.

➤The Warm Group

The warm group (586076 candidates)

↓ Equations(5)

$$\mathrm{EW}_{\mathrm{C_2}(\lambda 5165\ \text{Å})} < 10.0 \times \mathrm{EW}_{\mathrm{C_2}(\lambda 4737\ \text{Å})} + 6.0,$$
$$\mathrm{EW}_{\mathrm{C_2}(\lambda 5165\ \text{Å})} > 0.3 \times \mathrm{EW}_{\mathrm{C_2}(\lambda 4737\ \text{Å})} - 2.0,$$
$$\mathrm{EW}_{\mathrm{C_2}(\lambda 5165\ \text{Å})} > -1.0 \times \mathrm{EW}_{\mathrm{C_2}(\lambda 4737\ \text{Å})} + 6.0.$$

127943 candidates

↓ Equations(6)

$$\mathrm{EW}_{\mathrm{CN}(\lambda 7065\ \text{Å})} < 1.2,$$
$$\mathrm{EW}_{\mathrm{C_2}(\lambda 5635\ \text{Å})} < 3.0.$$

85405 candidates

↓ Inspecting their spectra by eyes

2903 carbon stars

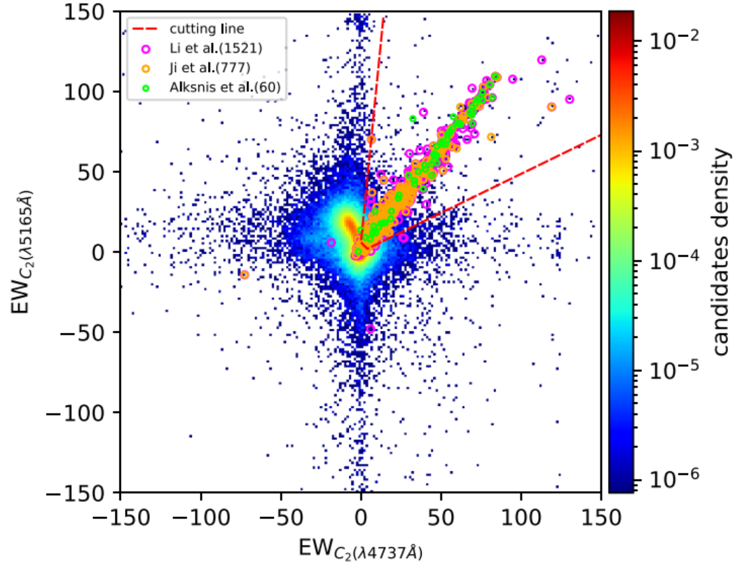


Figure 4. Distribution of the 586,076 warm candidates and the known carbon stars in the EW_{C2}(λ5635Å) vs. EW_{C2}(λ4737Å).

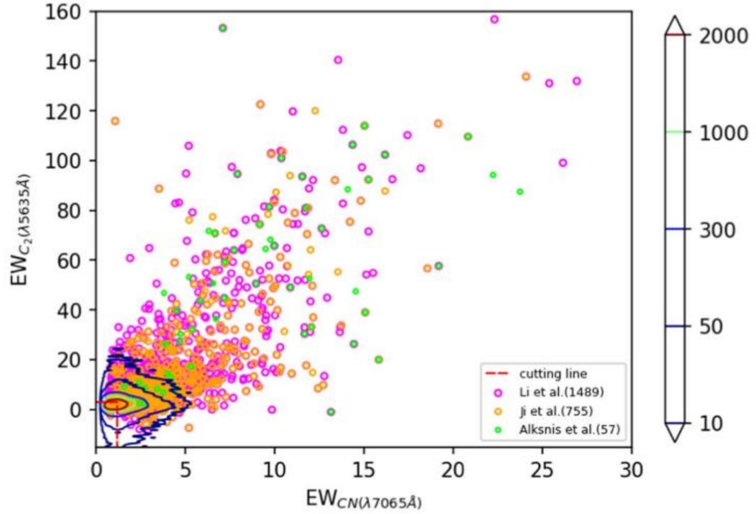


Figure 5. Distribution of the 127,943 warm candidates and the known carbon stars in the EW_{C2}(λ5635Å) vs. EW_{CN}(λ7065Å) plane.

➢The Cool Group

The cool group (23629 candidates)

↓ Equations(7) $EW_{CN(\lambda 7820\ \text{Å})} > 4.8.$

5304 candidates

↓ Inspecting their spectra by eyes

575 carbon stars

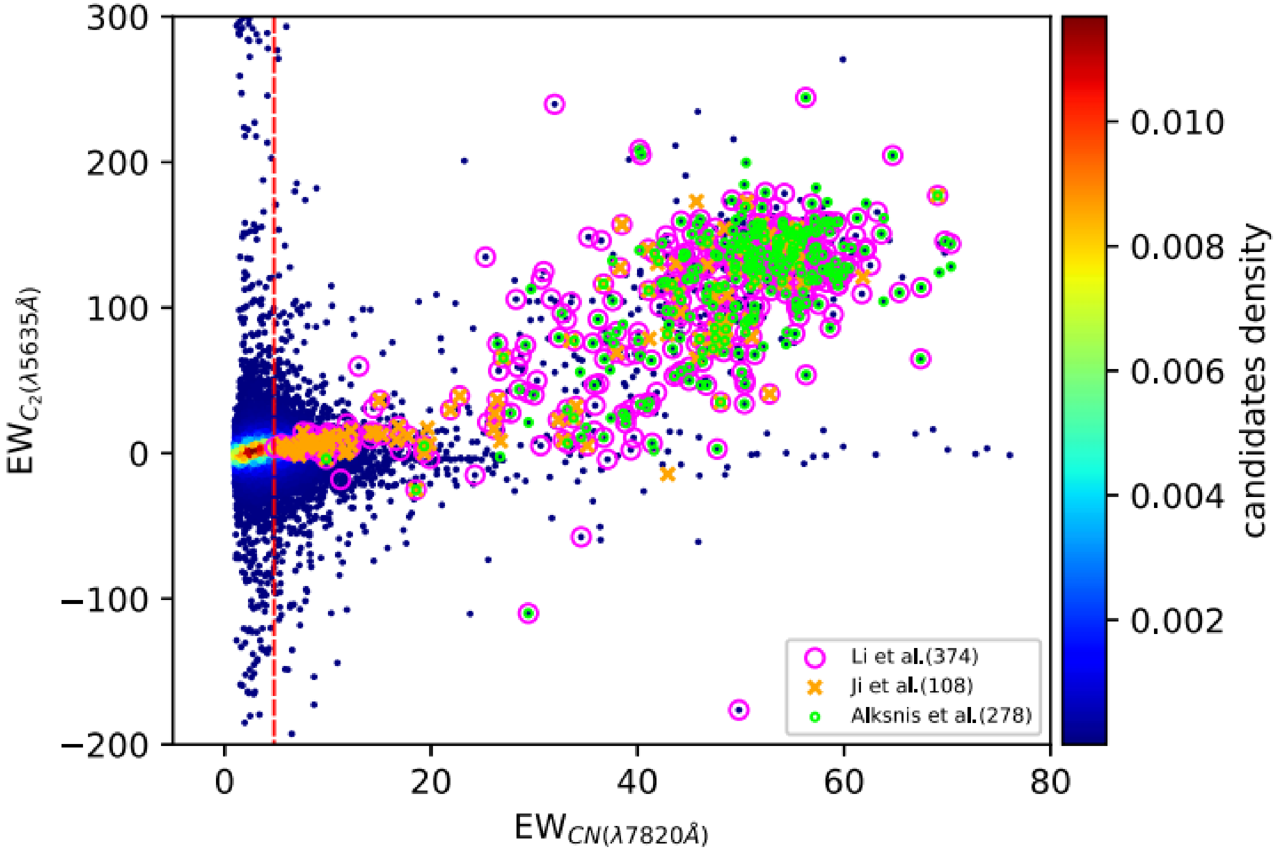


Figure 6. Distribution of 23,629 cool candidates and known carbon stars in the EW_{C2}(λ5635Å) vs. EW_{CN}(λ7820Å) plane.

➢3.2 Spectral Classification

- For the spectral classification of carbon stars in this work, we adopt the latest carbon star classification system published by Barnbaum et al. (1996).

1: C–H Stars

- Strong G band at λ4300 Å.
- Secondary P-branch head near λ4342 Å as a distinctive feature.
- Weak Fe I line at λ4383 Å.
- Strong Ba II lines at λ4554 Å and λ6496 Å.

2: C–R Stars:

- Strong CN absorption band at λ4215 Å.
- Prominent Ca I line at λ4226 Å.
- Very weak Ba II lines at λ4554 Å and λ6496 Å.

3: C–N Stars:

- Almost no flux below λ4400 Å, or even λ5000 Å, a key identifier.
- Isotopic bands are generally weak.
- Enhanced lines of s-process elements, especially Ba, more than in C–R stars.

4: Ba Stars:

- Significant enhancement of s-process elements.
- Strong Ba II line at λ4554 Å and Sr II line at λ4077 Å.

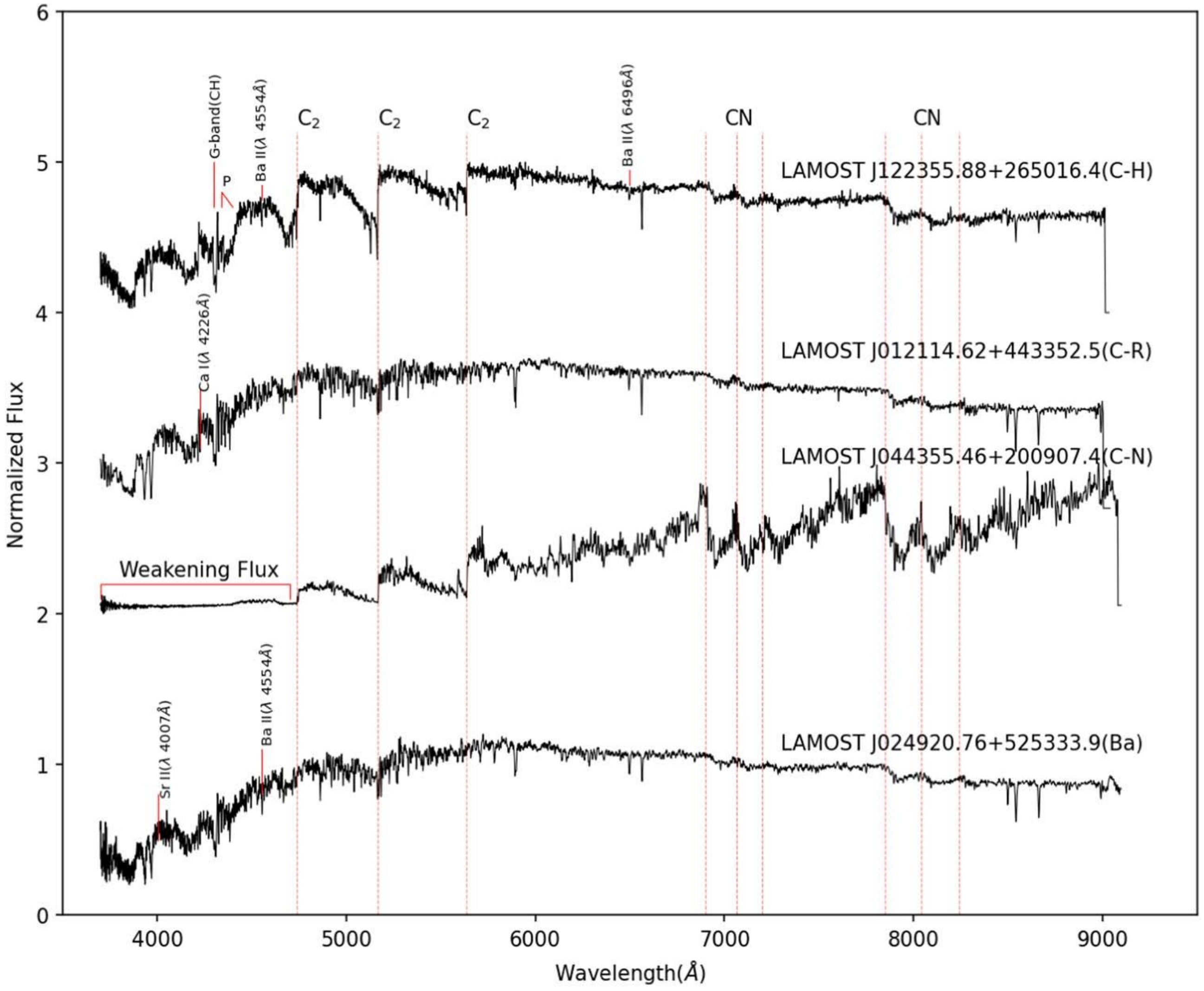


Figure 7. Four typical LAMOST spectra of carbon stars classified.

➢3.3 Identification Results

Table 2
Carbon Stars in This Work

Subtype	Number of Carbon Stars	Number of Carbon Stars Spectra
C–H	925	1217
C–R	284	341
C–N	608	799
Ba	1292	1657
UNKNOWN	437	528
Total Number	3546	4542

They manually classify 4542 spectra of 3546 carbon stars identified in LAMOST DR7.

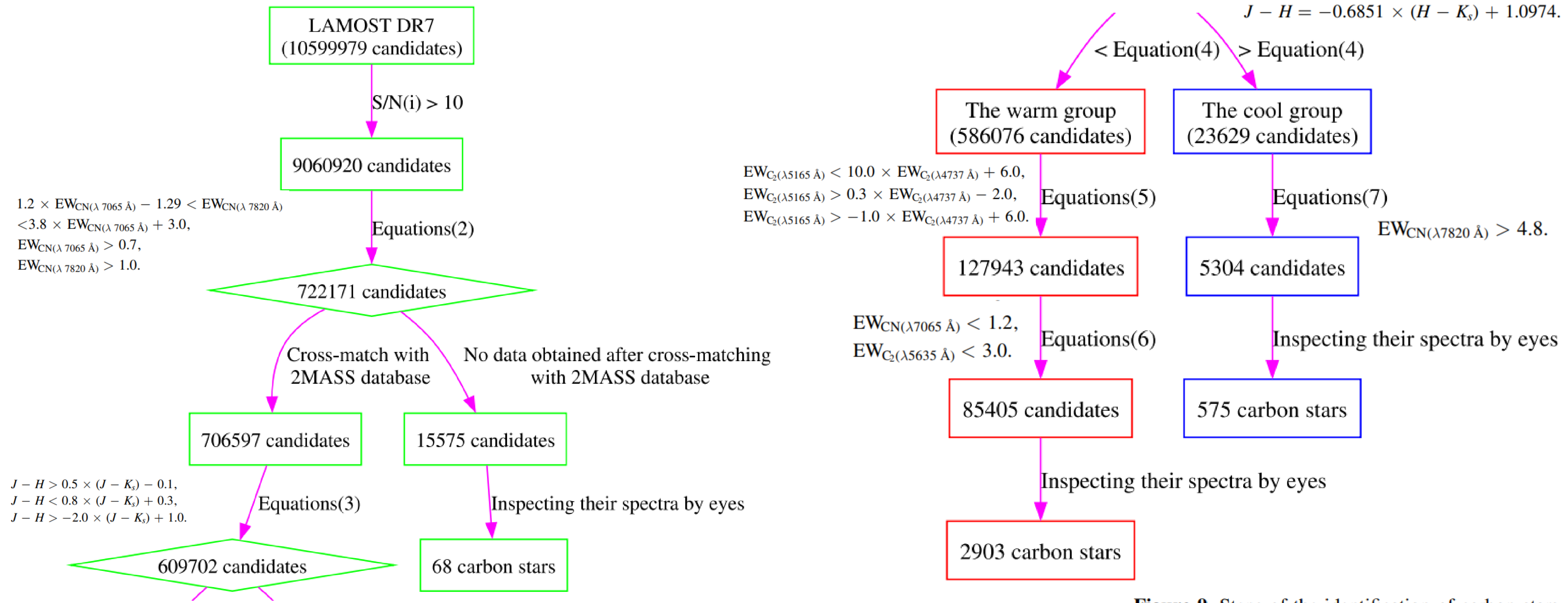


Figure 9. Steps of the identification of carbon stars.

4.1 Distribution of Carbon Stars

- JHKs colors are a good indicator of effective temperature (Wang & Jiang 2014); therefore, they are often used to distinguish subtype carbon stars with different temperatures.

- Previous works have shown that many carbon stars are actually carbon dwarf stars (Green 2013; Green et al. 2019; Roulston et al. 2022).

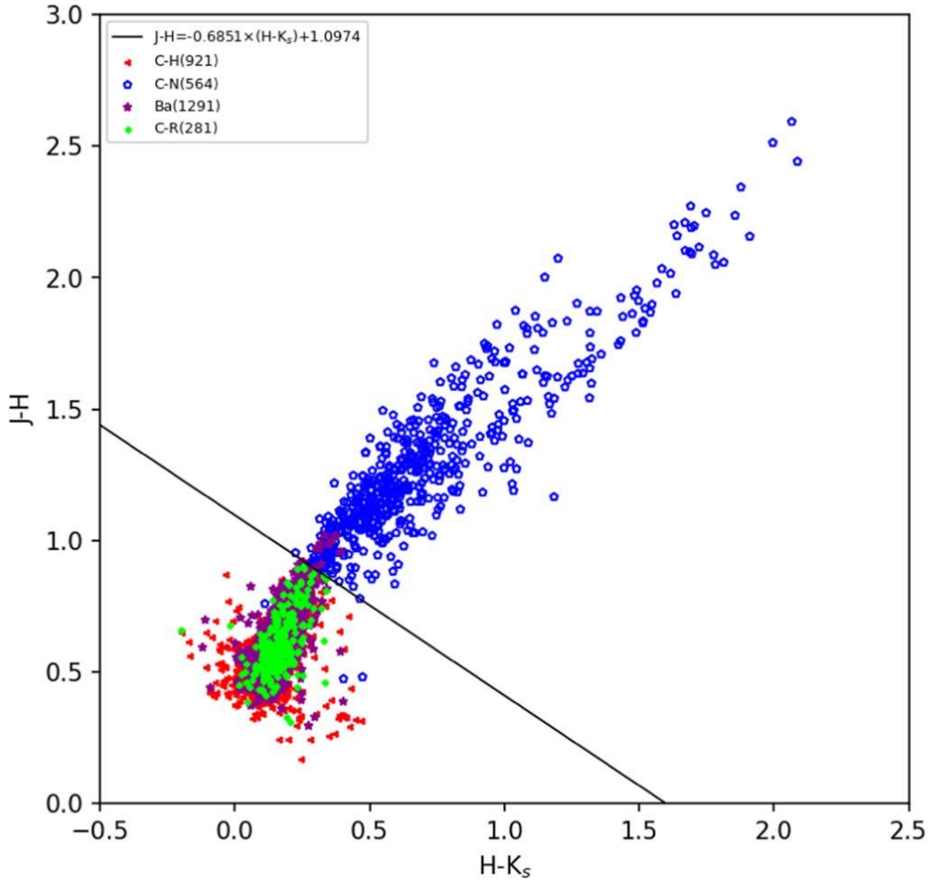


Figure 10. Distribution of our carbon stars in the J − H vs. H− Ks diagram.

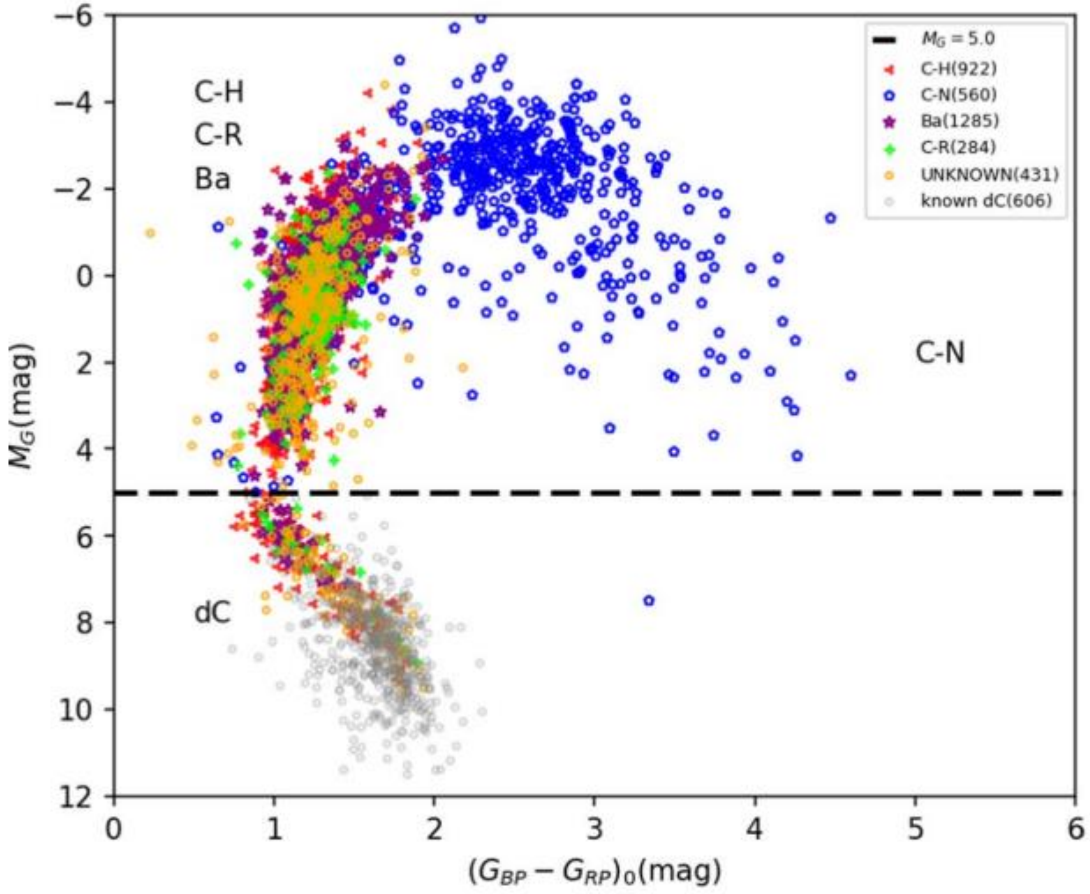


Figure 11. Distribution of our carbon stars in the H-R diagram.

4.2 Spatial Distribution

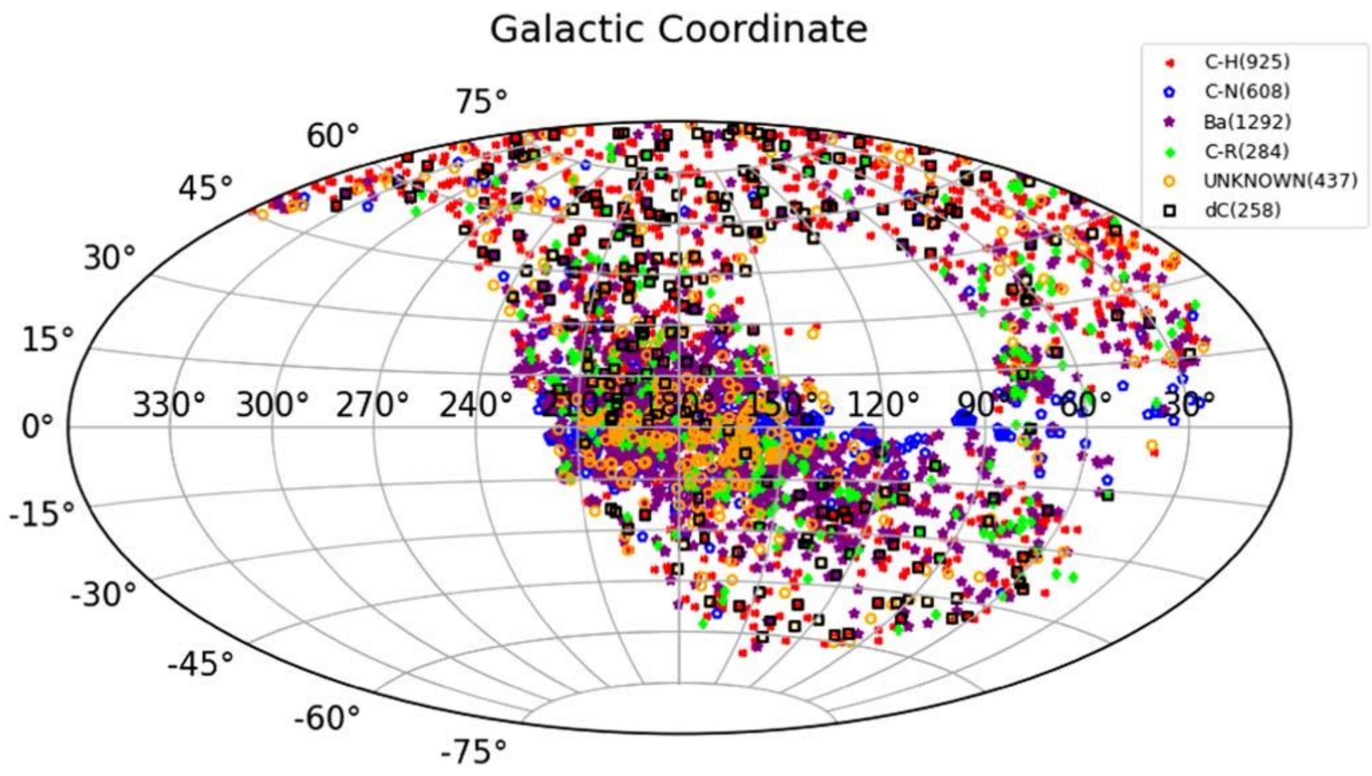


Figure 13. Spatial distribution of the 3546 carbon stars reported in this paper in the Galactic coordinates.

The majority of C–N (95%) and a C–R (72%) and Ba stars (84%) are concentrated at low Galactic latitudes.

A majority of the C–H stars and dC stars (70.9%) lie in high Galactic latitudes.

dC stars are from the older thick-disk and halo populations (Farihi et al. 2018; Roulston et al. 2022).

Summary

- From over 10 million low-resolution spectra in LAMOST DR7, we identified 3546 carbon stars (4542 spectra), including 925: C–H, 1392: Ba, 608: C–N, and 284: C–R stars, with 437: unclassified carbon stars marked as "UNKNOWN".

- By mapping carbon star candidates in the H-R diagram, we identified 258 dwarf carbon star candidates from the 3546: carbon stars, comprising 33: Ba, 104: C–H, 21: C–R, and 100: "UNKNOWN" stars.

- We discussed the spatial distribution of each subtype of carbon star in the Milky Way, finding that most carbon stars are distributed in the anti-galactic direction, related to LAMOST's sky survey strategy. The spatial distribution confirms that C–H stars are primarily found in halo populations, while C–N, C–R, and Ba stars are mostly distributed at low Galactic latitudes. Among the 437 "UNKNOWN" stars, about 40% are located in regions with $|b| \geq 30°$.

Thanks