New Orbital Parameters of 850 Wide Visual Binary Stars and Their Statistical Properties Postprint

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Date: 2025-02-25T00:00:00+00:00

Abstract

Based on positional observations and measurements of radial velocities, the orbits of 850 wide visual binary stars have been determined. The parameters of the log-normal distributions for the histograms of orbital periods, stellar masses, and semimajor axes in astronomical units have been obtained. The eccentricity histogram for binary stars with orbital periods less than 400 yr follows a normal distribution centered at e = 0.545 +/− 0.029. For stars with longer periods, this distribution obeys the law f = 2e, with accuracy to errors. The mass-to-luminosity relation for stars with well-determined masses are the luminosity and mass of the star in units of the solar luminosity and mass, respectively.

Full Text

Preamble

Research in Astronomy and Astrophysics, 25:015012 (18pp), 2025 January

https://doi.org/10.1088/1674-4527/ad9197
CSTR: 32081.14.RAA.ad9197

The LAMOST Spectroscopic Survey of Supergiants in M31 and M33

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Received 2024 June 05; revised 2024 October 16; accepted 2024 November 05; published 2025 January 8

Abstract

We present systematic identifications of supergiants in M31 and M33 based on the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) spectroscopic survey. Radial velocities of nearly 5000 photometrically selected M31/M33 supergiant candidates have been properly derived from the qualified spectra released in LAMOST DR10. By comparing their radial velocities with those predicted from the rotation curve of M31, as well as utilizing Gaia astrometric measurements to exclude foreground contaminations, we have successfully identified 199 supergiant members in M31, including 168 "Rank1" and 31 "Rank2" candidates. This sample contains 62 blue supergiants (BSGs, all "Rank1"), 134 yellow supergiants (YSGs, 103 "Rank1" and 31 "Rank2"), and three red supergiants (RSGs, all "Rank1"). For M33, we identify 84 supergiant members (56 "Rank1" and 28 "Rank2"), which include 28 BSGs (all "Rank1"), 53 YSGs (25 "Rank1" and 28 "Rank2"), and three RSGs (all "Rank1"). These constitute the largest supergiant samples of M31/M33 with full optical wavelength coverage ($3700 < \lambda < 9100$ Å). This sample is valuable for understanding star formation and stellar evolution under different environments.

Key words: galaxies: individual (M31, M33) -galaxies: stellar content -(galaxies:) Local Group -stars: evolution -stars: massive -(stars:) supergiants

1. Introduction

Supergiants represent the evolutionary phases of massive stars (>8 M) and are extremely rare but of great interest due to their importance in constraining stellar evolutionary theory (e.g., Massey & Olsen 2003; Neugent et al. 2010; Massey et al. 2013, 2016) and their profound feedback effects on the overall evolution of their host galaxies (e.g., Oey & Clarke 2009).

Several distinct evolutionary stages following the termination of the main sequence for massive stars can be classified according to their locations on the Hertzsprung-Russell (H-R) diagram (see Figure 1 [Figure 1: see original paper], where the evolutionary tracks are taken from Ekström et al. 2012). As shown in Figure 1, blue supergiants (BSGs) occupy the luminous blue range and represent a mix of hot main sequence stars and more evolved BSGs, including the evolved descendants of the most massive O-type stars: Wolf-Rayet stars (WRs). Additionally, for the most luminous portion of the blue region, the classical luminous blue variables (LBVs) phase represents the next stage for the most massive stars (e.g., M > 30-60 M), which exhibit spectacular eruptions with several magnitudes of visual enhancement and eject large amounts of material (see, e.g., Bohannan 1997; Conti 1997). In the central region of the H-R diagram, bounded by the two black dashed lines marked in Figure 1, yellow supergiants (YSGs) are located. These are F/G-type supergiants with effective temperatures (T_{eff}) roughly from 4800 to 7500 K and luminosity log L/L > 3.5. The YSG stage is short-lived and can evolve either directly from main sequence massive stars or back from red supergiants (RSGs) for stars with initial masses between 8 and 30 M . Finally, RSG phases (K/M-type supergiants) occupy the cool (or red) region of the H-R diagram and represent relatively longer-lived evolved descendants of moderately massive (8-25 M) stars.

Modeling the evolutionary tracks of massive stars remains difficult, primarily due to the complicated mass loss process, which is still somewhat uncertain, and substantial work (both theoretical and observational) is required to fully understand this process (e.g., Massey 2013; Smith 2014). Systematic searches for and studies of supergiants in Local Group (LG) galaxies—which serve as perfect laboratories with simple variables such as chemical compositions—will provide important clues for constraining theoretical models of stellar evolution. Additionally, studies of supergiants in LG galaxies help us understand their profound feedback effects that influence the evolution of these galaxies themselves (reviewed by Oey & Clarke 2009).

To systematically identify supergiants in LG galaxies, Massey et al. (2006, 2007) carried out the Local Group Galaxies Survey (LGGS) to obtain UBVRI photometry with precision better than 1%-2% for the two spiral galaxies M31 and M33, and for seven irregular galaxies: IC 10, NGC 6822, WLM, Sextans A, Sextans B, Pegasus, and Phoenix. With precise photometry, one can select different types of supergiant candidates based on color-magnitude or color-color diagrams. However, foreground contamination effectively hampers the selection of supergiants through photometry alone, especially for YSGs. Additionally, it is difficult to obtain accurate physical properties for those supergiants with only photometric information available. Fortunately, spectroscopy can neatly solve these problems. Using the Hectospec spectrograph equipped with 300 optical fibers mounted on the MMT 6.5 m telescope, Drout et al. (2009, 2012) carried out systematic identifications of YSGs in M31 and YSGs/RSGs in M33, respectively. Using the Hydra multi-object fiber spectrograph on the WIYN 3.5 m telescope, Massey et al. (2009) systematically searched for RSGs in M31. Most recently, Massey et al. (2016) conducted a more comprehensive search for supergiants in M31 and M33 using the Hectospec spectrograph mounted on MMT. By combining these efforts, Massey et al. (2016) constructed a large catalog of 700/1200 supergiant candidates in M31/M33.

Despite significant progress in searching for supergiants in M31/M33 over the past several years by Massey' s group, the current supergiant sample remains incomplete because: (1) the number of photometrically selected supergiant candidates is quite large and difficult to identify spectroscopically in full; and (2) the wavelength coverage of current spectra does not include the full optical range and is therefore insufficient for further studies, such as metallicity estimates (Liu et al. 2022).

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, also named the Guoshoujing Telescope; Cui et al. 2012) is a 4 m quasi-meridian reflecting Schmidt telescope equipped with 4000 fibers, each with an angular diameter of 3.3 arcseconds projected on the sky, distributed in a circular field of view (FoV) of 5° in diameter. The LAMOST spectroscopic survey (Deng et al. 2012; Zhao et al. 2012; Liu et al. 2014) offers a huge advantage for systematically searching for supergiants in M31/M33 because: (1) LAMOST is one of the telescopes with the highest spectral acquisition rate—by the end of 2022, LAMOST had accumulated more than 21 million spectra, consisting of 11 million low-resolution spectra (LRS) and 10 million medium-resolution spectra (Yan et al. 2022); (2) the FoV of LAMOST is nearly the size of M31/M33; and (3) the spectrographs used by the LAMOST spectroscopic survey yield spectra covering the entire optical range ($3700 < \lambda < 9100$ Å) with moderately low resolution (R 1800).

In this study, we present our systematic identification of supergiants in M31/M33 utilizing LAMOST Data Release 10 (DR10) data. Our approach involves the initial selection of photometric candidates through LGGS and Gaia photometry, described in Section 2. Subsequently, spectroscopy from LAMOST and astrometry from Gaia are used to select true members in Section 3. In Section 4, we present the results and provide discussion. Finally, a summary is presented in Section 5.

2. Target Selection and Observations

As an extension of the LAMOST Spectroscopic Survey of the Galactic Anticentre (LSS-GAC; Liu et al. 2014), the M31 and M33 areas ($0° <$ R.A. $< 30°$ and $25° <$ decl. $< 50°$) were systematically observed by LAMOST. The detailed survey strategy and target selections are described in Yuan et al. (2015). In particular, potentially luminous M31/M33 sources (such as planetary nebulae, H II regions, globular clusters, and supergiant stars) and background quasars were observed with high priority. In this work, we utilized LAMOST DR10 LRS data, which is a collection of spectra obtained from 2011 October to 2022 June. Here, our focus is on the supergiants in M31/M33 that are mainly located in the disk regions of the two galaxies. Therefore, hereafter the M31/M33 area refers to approximately 3/1.5 square degrees around their centers (R.A. = 10.68458°, decl. = 41.26875° for M31 and R.A. = 23.46208°, decl. = 30.65994° for M33; Jarrett et al. 2003).

Figure 1 [Figure 1: see original paper] shows the evolutionary tracks of massive stars (M > 8 M) for solar metallicity (z = 0.014), assuming an initial rotation velocity of 40% of the critical break-up speed, taken from Geneva evolutionary tracks (Ekström et al. 2012). The evolutionary tracks with different initial masses are labeled with different colors. The two black vertical dashed lines represent the YSG region, located at 4800 < T_{eff} < 7500 K. Other evolutionary phases (BSGs, RSGs, WRs, and LBVs) are also labeled at their corresponding locations.

2.1. Photometric Selection Criteria

Here we introduce the detailed target selection of our supergiant candidates in M31/M33 from LAMOST DR10. First, the LGGS photometry catalog is cross-matched with LAMOST DR10, resulting in 1514 common sources for M31 and 981 for M33. Subsequently, by applying criteria from previous studies (mainly from Massey' s group; e.g., Massey et al. 2006, 2009; Drout et al. 2009, 2012), the different types of supergiant candidates are selected as follows.

YSG candidates: The greatest difficulty in selecting blue massive stars using photometry is dust reddening. Although foreground extinction is negligible for the entire M31 [E(B − V) = 0.06] and M33 [E(B − V) = 0.07] (van den Bergh 2000), the internal dust of these two gas-rich galaxies themselves makes those blue massive stars heavily and inhomogeneously reddened. The Johnson Q-index, as defined in Equation (1), is a reddening-free indicator (at least for Q < −0.6) of intrinsic color that can effectively select blue massive supergiants (Massey et al. 2016). For YSGs, the photometric cuts in Equations (2)-(3) only indicate their possible locations on a color-color diagram, and a large number of foreground contaminations unavoidably remain. The identification of real YSGs therefore relies heavily on results from spectroscopy or astrometry.

RSG candidates: Foreground contamination also poses a challenge in identifying RSGs in M31/M33, but the color-color diagram (see Equation (5); Massey 1998; Drout et al. 2012) using B − V and V − R can effectively distinguish RSGs from dwarfs, especially for V − R > 0.6. This is simply because V − R is sensitive to effective temperature and B − V is sensitive to both effective temperature and surface gravity.

The LGGS photometry has several caveats in selecting supergiant candidates: (1) the bright end of LGGS is incomplete; (2) LGGS does not cover the entire M31/M33 sky region; and (3) one or more bands of UBVRI are missing for some sources in the LGGS catalog. To address the first issue, we incorporated objects from Magnier et al. (1992) at the bright end. For the second and third cases, we utilized Gaia Data Release 3 (DR3) broadband G/GBP/GRP photometry to select supergiant candidates using the criteria developed by Salomon et al. (2021). Notably, these criteria merely represent the positions of different types of supergiants on the color-color diagram, and candidates selected this way may suffer substantial foreground contamination.

In addition to the above photometric criteria, three cuts related to LAMOST observations are applied. The first requires V or G magnitude (for those without V photometry) to be brighter than 20 to match the limiting magnitude of LAMOST. The second requires no nearby stars within 4.00 arcseconds (similar to the diameter of the LAMOST fiber) of the supergiant candidates, or if any exist, they should be at least 2 mag fainter, to exclude contaminants from close bright neighbors. The last cut requires the spectral signal-to-noise ratio (SNR) to be greater than 5, ensuring the quality of the spectrum for subsequent analysis. Finally, we excluded contaminants from M31/M33' s extended sources—i.e., globular clusters, planetary nebulae, and H II regions—by cross-matching with catalogs from Chen et al. (2015), the M31 Revised Bologna Clusters and Candidates Catalog (Galleti et al. 2004, 2007, 2009) and Sarajedini & Mancone (2007), as well as catalogs from Yuan et al. (2010), Azimlu et al. (2011), Sanders et al. (2012), Zhang et al. (2020), Hodge et al. (1999), and Ciardullo et al. (2004).

The number of M31/M33 supergiant candidates is summarized in Tables 1 and 2. The number of RSG candidates is very small due to their intrinsically faint luminosities, which are beyond the observational capability of LAMOST. The large number of YSG candidates is expected since photometric colors cannot distinguish YSGs from the substantial number of foreground contaminants.

3. Supergiant Identification

Here we introduce our methods for separating M31/M33 supergiants from foreground dwarfs. As mentioned earlier, separating M31/M33 supergiants from foreground dwarfs based solely on their positions on the color-magnitude diagram or intrinsic colors—especially for YSGs—is quite difficult (Drout et al. 2009). Fortunately, the kinematics of M31/M33 allow us to overcome this problem (Massey et al. 2009, 2016; Drout et al. 2009, 2012).

The two galaxies have large negative systemic radial velocities (approximately -300 km s^{-1} for M31 and -200 km s^{-1} for M33) and are both rotating systems. Following Drout et al. (2009, 2012), the radial velocity (RV) of M31/M33 members can be predicted according to their positions (X and R):

V_{exp} = f(X,R)

where X is the distance along M31/M33' s semimajor axis, and R is the radial distance of the object within the plane of M31/M33 (Drout et al. 2009, 2012). By comparing the expected RVs, V_{exp}, to the observed ones, M31/M33 members can be effectively selected from the contaminations.

3.1. Observed Radial Velocities from LAMOST LRS

In this study, 3936 spectra of a total of 3280 supergiant candidates in M31 and 1580 in M33 have been obtained from the LAMOST DR10 LRS. For sources with multiple observations, we take the one with the highest SNR. The RV measurements, as well as the stellar atmospheric parameters, are derived by the LAMOST stellar parameter pipeline (LASP; Luo et al. 2015). Through comparisons with RV measurements obtained from high-resolution spectroscopy and RV standard stars (Gao et al. 2015; Luo et al. 2015; Huang et al. 2018; Li et al. 2023), the zero offset of LAMOST LRS RV is found to be around -5 km s^{-1}, with typical precision also around -5 km s^{-1}.

As an independent check, the LAMOST LRS RVs are compared to those derived from MMT spectra by Massey' s group (Drout et al. 2009; Massey et al. 2009). Overall, they exhibit excellent consistency, with no significant trends detected along either SNR or stellar color $B - V$ (see Figure 2 [Figure 2: see original paper]). The scatter is only 6.79 km s^{-1} for stars with $SNR > 10$ and 11.46 km s^{-1} even at $5 < SNR < 10$. The overall median offset is -5.46 km s^{-1}, having excellent consistency with that found by the aforementioned studies. An offset of 5 km s^{-1} was therefore added to RVs derived from LAMOST LRS spectra.

3.2. Identifying Supergiants

Now armed with the observed RVs of our supergiant candidates, foreground contaminations can be eliminated by comparing expected RVs predicted from the rotation curve to the observed ones. In the left panel of Figure 3 [Figure 3: see original paper], two branches are clearly visible: the one with a nearly constant value of zero represents member stars of M31, while the significant diagonal branch indicates foreground field stars of the Milky Way. We note the two branches gradually overlap with increasing X, suggesting that candidates found in the northeastern corner may still suffer moderate contamination from foreground stars. A linear fit was performed for the diagonal branch (represented by the middle solid blue line in the left panel of Figure 3), and a Gaussian function was applied to the fitting residuals to determine their scatter σ; 210 objects falling below the diagonal branch minus 3σ are considered M31 supergiant candidates.

Among them, 185 were selected from LGGS or Magnier et al. (1992) and 25 were selected from Gaia DR3 photometry; 39 of these 210 candidates have been observed at least twice by LAMOST with $SNR > 5$. For these, we compare the RV values from different observations and remove four candidates with variation (defined as the difference between maximum and minimum) larger than 50 km s^{-1}. This number (4/39) also indicates that the foreground contamination among the M31 supergiant candidates identified with only one observation is no more than 10%. The spectra of the remaining 206 candidates are then visually inspected, and seven are discarded due to poor quality.

In principle, astrometric measurements from Gaia provide another way to distinguish supergiant members of M31 from foreground field stars. To do so, we utilize the numerous RSG candidates of M31 identified by Massey et al. (2021) based on near-infrared (NIR) colors and Gaia DR2 astrometry as a comparison sample. This comparison sample provides a reference for the distribution of parallax and proper motions of young disk-like objects (similar to those in this study) in M31. In total, nearly 4500 RSG candidates in M31 are found with astrometric information from Gaia DR3, with an average parallax of 0.06 ± 0.74 mas and mean proper motions in R.A. and decl. of -0.15 ± 1.19 and 0.03 ± 1.36 mas yr^{-1}, respectively.

Following a similar methodology to Massey et al. (2021), we identify foreground stars among the photometrically selected supergiant candidates (see Tables 1 and 2) with parallax or proper motions falling outside the region that contains 99.5% of the comparison sample. As clearly shown in Figure 4 [Figure 4: see original paper], the foreground stars defined this way are distributed largely (97.5%) in the diagonal branch of the RV differences diagram, with only a few falling below the diagonal branch minus 3σ. A similar case is found for M33. This result confirms the effectiveness of RV measurements for separating M31/M33 members from foreground contaminations.

Therefore, we combine both RV and Gaia astrometry criteria to select supergiant members. Candidates exhibiting RV differences below the diagonal branch minus 3σ, along with parallax and proper motions within the region containing 99.5% of the comparison sample, are classified as "Rank1" candidates. These candidates have successfully passed through two independent selection criteria, indicating a high level of credibility as true supergiant members of M31/M33. On the other hand, candidates with RV distributions similar to those of "Rank1" candidates but exhibiting significant deviation of parallax or proper motions from the mean values of the comparison sample are classified as "Rank2" candidates. In total, there are 168 "Rank1" and 31 "Rank2" supergiant candidates in M31, represented as blue dots and red diamonds in the left panel of Figure 3, respectively.

Employing the same methodology for M33, we conducted a selection of supergiant candidates. We began by comparing the observed and expected RVs of the photometrically selected supergiant candidates of M33, deriving the best linear regression for objects within the diagonal line and the corresponding scatter σ, as shown in the right panel of Figure 3; 85 objects falling below the diagonal branch minus 3σ were selected as M33 supergiant candidates. Of the 85 candidates, 17 were observed more than once by LAMOST with $\mathrm{SNR} > 5$, and none show RV variation larger than 50 km s^{-1}. After visual inspection of their spectra, one candidate is excluded due to poor quality. Subsequently, we utilized approximately 2100 M33 RSG candidates from Massey et al. (2021) with available Gaia DR3 astrometric measurements as a comparison sample to double-check foreground contaminations. Following the same procedure used for M31, we identified 56 "Rank1" and 28 "Rank2" M33 supergiant candidates, represented by blue dots and red diamonds, respectively, in the right panel of Figure 3.

3.3. Membership Properties and Re-examination

In Figures 5 and 6, we present the RV and spatial distribution, as well as the color-magnitude diagram, of different supergiant candidate types in M31/M33. Note that the color-magnitude diagram in the right panel does not contain candidates without B and V photometry. In the left panel, it is evident that the majority of BSGs and RSGs are located near the region where RV differences are approximately zero, indicating excellent agreement between observed and predicted RVs. In contrast, a fraction of YSG candidates show observed RVs that deviate from the predicted values. Additionally, YSG candidates are more widely distributed in the disks of M31/M33 compared to BSGs and RSGs. Furthermore, in the color-magnitude diagrams, the bluest YSGs in both M31 and M33 extend into the BSG region. This extension is consistent with our loosening of the original color selection to include stars as blue as B − V = 0, similar to the criteria set by Drout et al. (2009).

Considering that the RVs of quite a few YSG candidates deviate from the predicted values, it is essential to re-examine the spectra of those YSGs to validate their membership in M31. The presence of the O I \$ \$7774 triplet serves as a robust indicator for identifying YSGs. The O I \$ \$7774 triplet is known for its strong luminosity effect in F-type supergiants due to non-local thermodynamic equilibrium (non-LTE) effects (Osmer 1972). The strengths of O I \$ \$7774 can be accentuated by spherical mass outflows typical of supergiants (Przybilla et al. 2000). Candidates exhibiting this feature are considered firm YSGs (Drout et al. 2009). Unfortunately, this feature is difficult to detect in LAMOST spectra due to low SNR and sky emission subtraction issues. Only nine spectra of YSGs show significant O I \$ \$7774 absorption lines. In the future, follow-up high-quality spectroscopy will be required to confirm the memberships of those YSG candidates, especially those not sitting around the zero line region in the RV distribution diagram.

3.4. Comparison with Previous Studies

As mentioned in Section 1, Massey’ s group has conducted a series of studies to identify supergiant members. Therefore, we cross-matched our candidates with the catalogs published by Massey et al. (2016) and Massey et al. (2021). In total, we found that among the 168 “Rank1” candidates of M31, 87 had been studied by Massey’ s group and were already in the catalog from Massey et al. (2016), with two additional RSG candidates included in the catalog by Massey et al. (2021) through NIR photometry. Among those 87 candidates, 63 were identified as members, possible members, or unknown, while the other 24 objects were classified as foregrounds by Massey et al. (2016). These 63 candidates, together with the two RSG candidates identified through NIR, are referred to as “Massey members.” Conversely, for those 24 objects classified as foregrounds by Massey et al. (2016), we designate them as “Massey non-members.”Additionally, six “Massey members”and seven “Massey non-members” are found among our 31 “Rank2” M31 supergiant candidates. For M33, the 56

"Rank1" supergiant candidates include 36 "Massey members" and one "Massey non-member." Among the 28 "Rank2" candidates of M33, there are five "Massey members" and 12 "Massey non-members." We note that most of these "Massey non-members" are YSGs.

We examined the RV distribution of those "Massey non-members" in Figure 7 [Figure 7: see original paper]. The RV differences of most are very close to the diagonal branch minus 3σ. Considering that none are confirmed with the O I $ $7774 triplet, their memberships in M31/M33 require further observational exploration as suggested earlier.

4. Results and Discussion

We present the supergiant candidates identified in this work in Tables A1 and A2. A more detailed version of the catalogs, including R.A., decl., and LAMOST observation times with SNR > 5, is available in electronic form in the online version of this manuscript.[8]

4.1. Physical Properties and HR-Diagram

To examine the distribution of our M31/M33 supergiant candidates within the H-R diagram and check their consistency with current stellar evolutionary tracks, it is essential to derive their effective temperatures and bolometric luminosities. For early-type candidates with B and V photometry available in M31, we apply a constant reddening correction of $\mathrm{E(B-V)} = 0.13$, which is the median value in M31 from Massey et al. (2007) and is widely employed in analyses of M31' s supergiants. For stars with Gaia photometry, the reddening coefficient is taken from Huang et al. (2021). As our candidates, mostly BSGs and YSGs, cover a wide range of dereddened colors from -0.25 to 2.31, they span a wide range of effective temperatures. Drout et al. (2009) provided transformations using the "Atlas9" model (Kurucz 1992) for objects with $0.03 \leq (\mathrm{B-V})_0 \leq 1.26$. A significant fraction of our candidates fall outside this range. Consequently, we opt to employ data from the YBC database (Chen et al. 2019) to derive effective temperature-color relations and bolometric correction (BC) with a wide application range of color. The BC values in different temperature ranges in the YBC database are optimized results provided after comparing results derived from various models (more details are in Chen et al. 2019). Additionally, the YBC database allows selection of different stellar masses and metallicities. By restricting the initial mass within the typical range for supergiants and fixing the metallicity as 2 Z , we obtain the corresponding transformation from dereddened colors to effective temperatures, encompassing a broader color range of $-0.37 \leq (\mathrm{B-V})_0 \leq 1.53$, as well as the BCs. Note that three RSGs are not included in the transformation process due to their extremely high $\mathrm{B-V}$ values and therefore are not included in the H-R diagram below.

The relationship between $(\mathrm{B-V})_0$ and log T_{eff} for supergiant candidates in M31 is as follows:

log T_{eff} = f($(B-V)_0$)

For M33 candidates selected based on Gaia, the transformation and BC for objects with $(B-V)_0$ ranging from 0.2 to 1.4 are as follows:

log T_{eff} = g($(B-V)_0$)

The corresponding BCs are:

BC = h($(B-V)_0$)

For candidates with only Gaia photometry available, we establish a similar transformation from (G_{BP} − G_{RP})$_0$ to log T_{eff} and the corresponding BC values for (G_{BP} − G_{RP})$_0$ ranging from −0.1 to 1.24, based on data from the YBC database:

log T_{eff} = i((G_{BP} − G_{RP})$_0$)

For M33 candidates, we apply a constant reddening correction of $E(B-V) = 0.12$ and compute the transformation relationship based on the YBC database. We set the metallicity as 0.6 Z , in line with Drout et al. (2012). For candidates with B and V photometry available, the relationship between $(B-V)_0$ and log T_{eff} is as follows:

log T_{eff} = j($(B-V)_0$)

The BCs are:

BC = k($(B-V)_0$)

Applying distance moduli of 24.40 and 24.60 for M31 and M33, respectively, from van den Bergh (2000), we derive the bolometric luminosities of all "Rank1" and "Rank2" supergiants in M31/M33.

In Figure 8 [Figure 8: see original paper], we present the locations of M31/M33 supergiant candidates in the H-R diagram. Geneva evolutionary tracks for 2 Z and 0.6 Z , with an initial rotation speed of 40% of the breakup speed, are overplotted (Yusof et al. 2022; Eggenberger et al. 2021). Notably, in the left panel of Figure 8, there are four "Rank2" YSG candidates of M31 with extremely high luminosities inconsistent with the evolutionary tracks. A similar scenario is observed in the right panel, where the four most luminous "Rank2" YSGs deviate from the evolutionary tracks. Considering their "Rank2" properties and lack of O I $ $7774 triplet confirmation in their spectra, we doubt their status as genuine YSGs, and further confirmation is required. The locations of other supergiant candidates exhibit excellent agreement with the evolutionary tracks.

In the left panel of Figure 8, the most massive "Rank1" candidate of M31 is LAMOST J0043+4124, highlighted by a green box, with a mass over 40 M . This object has the brightest apparent G magnitude among our "Rank1" candidates and is located in a region where expected RVs are greater than −100 km s^{-1}, where M31 members and foreground stars may not be well separated by RVs alone (Hartmann & Burton 1997). However, considering that it passes both the RV and Gaia astrometry criteria successfully, we retain it as a YSG candidate. In M33, the most massive among the new “Rank1” candidates is a BSG, J0134+3044. Highlighted by a green box in the right panel of Figure 8, it is estimated to be more than 32 M based on evolutionary tracks, and this object has been analyzed by Liu et al. (2022) through spectroscopic methods. The effective temperature and bolometric luminosity derived by Liu et al. (2022) agree with our estimations in this work, indicating the reliability of our newly derived transformation relations.

4.2. Spatial Distribution and Possible Substructures

In Figure 9 [Figure 9: see original paper], we present the spatial distribution of our “Rank1” and “Rank2” supergiant candidates in Herschel SPIRE 250 m (Fritz et al. 2012) and H I 21 cm (Braun et al. 2009) images of M31. In the left panel, the majority of supergiant candidates fall along the CO ring, which corresponds to the high star formation region, in line with our expectations. Additionally, several supergiant candidates are found outside the CO ring, including two extended substructures of M31’s disk. One is in the southwestern corner, already validated as part of M31 (Braun et al. 2009; Fritz et al. 2012). This substructure is highlighted by a yellow box in Figure 9, and the LBV found by Huang et al. (2019) is situated within it. The other substructure is located in the northeast corner and includes 11 candidates, highlighted by a white box in Figure 9 and commented as “NE” in Table A1. Among these candidates, 10 are YSGs (nine “Rank1” and one “Rank2”) and one is a BSG (“Rank1”).

In the right panel, these candidates are found near the gas ring. This region faces significant contamination from foreground Galactic emission, suggesting the observed gas may predominantly originate from the Milky Way, not M31 itself. Fritz et al. (2012) analyzed this region using Herschel far-infrared data, correcting for the foreground dust component, but could not conclusively determine whether the substructure belongs to the Galactic foreground or M31. If follow-up observations confirm that the 11 supergiant candidates are members of M31, it would provide strong evidence for the ownership of this substructure. This will be a significant component of our future work.

In the left panel of Figure 10 [Figure 10: see original paper], we present the spatial distribution of our supergiant candidates in the Herschel SPIRE 250 m image of M33. Similar to M31, the majority of supergiant candidates are distributed along the CO ring. Additionally, four YSG candidates (two “Rank1” and two “Rank2”) are positioned in the southwestern corner of M33 and commented as “SW” in Table A2. To investigate whether there are supporting substructures for these potential supergiant members, we use an image from the GALEX NUV band, as shown in the right panel of Figure 10. An extended substructure originating from M33’ s disk is visible, marked by a white dashed box. Three YSG candidates are located on the edge of this substructure. As part of our future work, we plan to conduct follow-up observations for these candidates to further analyze this possible substructure.

5. Summary

Based on LAMOST DR10 data, we conducted a systematic identification of supergiant members in M31 and M33. First, objects in M31/M33 from LAMOST DR10 were cross-matched with the LGGS catalog or Gaia DR3 to acquire their photometric data. BSG, YSG, and RSG candidates were then selected based on criteria adopted from previous studies. Subsequently, we excluded foreground field stars by comparing observed RVs to expected ones, as well as using Gaia astrometry. In total, we identified 199 supergiant candidates in M31, with 168 "Rank1" and 31 "Rank2." For M33, we found 84 supergiant candidates, including 56 "Rank1" and 28 "Rank2." Our future work involves conducting follow-up spectroscopy for YSG candidates with low SNR to determine their memberships.

We constructed color-effective temperature and BC relations based on the YBC database to derive the effective temperatures and BCs of the candidates, and examined their distribution in H-R diagrams. Furthermore, we checked the consistency between the locations of supergiant candidates and those expected from Geneva evolutionary tracks. The results revealed agreement, especially for "Rank1" candidates.

Upon analyzing the spatial distribution of candidates, we identified a potential substructure in the northeastern corner of M31 and another in the southwestern corner of M33. The northeastern corner of M31 suffers significant contamination from Galactic emission, posing challenges in determining whether the substructure belongs to M31 or is dominated by foreground emission. Follow-up validation of supergiant candidates within this substructure is crucial. Once confirmed, it would substantially contribute to ascertaining the ownership of the substructure. Likewise, the substructure in the southwestern corner of M33, along with the supergiant candidates within it, also requires further analysis. These will be crucial aspects of our future research.

Acknowledgments

This work was funded by the National Natural Science Foundation of China (NSFC, grant Nos. 12090040, 12090044, 12133001, and 12422303), Beijing Natural Science Foundation (no. 1242016), and the science research grants from the China Manned Space Project. This work was partially supported by the Talents Program (24CE-YS-08) and the Popular Science Project (24CD012) of the Beijing Academy of Science and Technology.

This work has made use of data products from the Guo Shou Jing Telescope (the Large Sky Area Multi-Object Fiber Spectroscopic Telescope, LAMOST). LAMOST is a National Major Scientific Project built by the Chinese Academy of Sciences. Funding for the project has been provided by the National Development and Reform Commission. LAMOST is operated and managed by the National Astronomical Observatories, Chinese Academy of Sciences.

Appendix

M31 and M33 Supergiant Candidates

Here we present our supergiant candidates of M31 and M33 identified in this work in Tables A1 and A2. A more detailed version of the catalogs has been published at http://www.scidb.cn/en/s/F3Yn2q.

Table A1: 199 Supergiants in M31

Star	RV (km s^{-1})	B − V	Note	Comment
J0037+4016	−450.1	−0.002	B9.5I+	Blue Supergiants
J0037+4020	−310.8	−0.073	B2.5Ia	
J0037+4021	−546.7	−0.008	O9.5I	
...	...	...	...	...
J0041+4110	−390.0	1.53	M2-3Ia:	Red Supergiants
J0043+4114	−286.1	1.45	M1-2Ia	
J0044+4155	−136.3	1.42	K5-7Ia	

Notes: A more detailed version, including R.A., decl., and LAMOST observation times with SNR > 5, is available in electronic form in the online version of this manuscript (see beginning of Section 4). Objects selected from LGGS are provided with LGGS names, while those from Magnier et al. (1992) or Gaia are labeled with "Mag" or "LAMOST" as a prefix before the coordinates.

Table A2: 84 Supergiants in M33

Star	RV (km s^{-1})	B − V	Comment
J0132+3034	−116.6	−0.005	Blue Supergiants
J0132+3024	−140.5	−0.096	WNE+B3
...	...	...	...
J0133+3030	−100.4	1.38	Red Supergiants
J0133+3100	−219.3	1.42	YSG::
J0134+3048	−106.7	1.45	YSG::

Note: A more detailed version, including R.A., decl., and LAMOST observation times with SNR > 5, is available in electronic form in the online version of this manuscript.

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[8] The online version has been published at https://www.scidb.cn/en/s/F3Yn2q.

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