A catalogue of H\(\alpha\) emission-line point sources in the vicinity fields of M 31 and M 33 from the LAMOST survey

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Abstract We present a catalogue of 3,305 H\(\alpha\) emission-line point sources observed with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) in the vicinity fields of M 31 and M 33 during September 2011 and January 2016. The catalogue contains 1,487 emission-line stars, 532 emission-line nebulae including 377 likely planetary nebulae (PNe), 83 H\(\text{II}\) regions candidates and 20 possible supernovae remnants (SNRs) and 1,286 unknown objects. Among them, 24 PN candidates, 19 H\(\text{II}\) region candidates, 10 SNR candidates and 1 symbiotic star candidate are new discoveries. Radial velocities and fluxes estimated from the H\(\alpha\) line and those quantities of seven other major emission lines including H\(\beta\), [O\(\text{III}\)] \(\lambda\)4959, [O\(\text{III}\)] \(\lambda\)5007, [N\(\text{II}\)] \(\lambda\)6548, [N\(\text{II}\)] \(\lambda\)6583, [S\(\text{II}\)] \(\lambda\)6717 and [S\(\text{II}\)] \(\lambda\)6731 lines of all the catalogued sources yielded from the LAMOST spectra are also presented in our catalogue. Our catalogue is an ideal starting point to study the chemistry properties and kinematics of M 31 and M 33.

Key words: galaxies: individual (M 31, M 33) — stars: emission-line — planetary nebulae: general — H\(\text{II}\) regions

1 INTRODUCTION

The Andromeda Galaxy (M 31), the closest spiral galaxy and the most dominant member of the Local Group, is always one of the most interesting targets for astronomers. The Triangulum Galaxy (M 33), located in the southeast of M 31 (about 15° away), is the third most massive member in the Local Group. A large number of work have been carried out to investigate the properties and to conjecture the accretion and evolution history of the stellar substructures and dwarf galaxies in the halo of M 31 and M 33 in recent years (e.g., [Ibata et al. 2001], [Ferguson et al. 2002], [Kalirai et al. 2006], [Gilbert et al. 2007], [Ibata et al. 2007], [Gilbert et al. 2009], [McConnachie et al. 2009], [Tanaka et al. 2010]) and references therein). Most of these studies are based on the photometric data. Due to the large distances of M 31 and M 33 (783 ± 25 kpc for M 31 and 809 ± 24 kpc for M 33; [McConnachie et al. 2005]), it is challenging for the present ground and space telescopes to give spectroscopic observations for the individual M 31 and M 33 objects, except for some very bright objects, such as the globular clusters and emission-line sources including the planetary nebulae (PNe) and H\(\text{II}\) regions. The emission-line objects, whose energies are concentrated on a few emission lines, are excellent tracers for the study of the kinematics and chemistry properties of their host galaxies.
Many efforts have been done to identify and study the emission-line objects in M31 and M33. More than 30 years ago, Nolthenius & Ford (1984) have identified 34 PNe in M31. Merrett et al. (2006) have presented a catalogue of 3,300 emission-line objects in the M31 area from the Planetary Nebulair Spectrograph Survey. 2,730 of them are likely PNe, including 2,615 objects belonging to M31 and the remaining objects associating with the satellite galaxies and substructures of M31. Azimlu et al. (2011) have studied the metallicity profile of M31 based on the spectra of hundreds of HII regions and PNe observed by the Multiple Mirror Telescope (MMT). Lin et al. (2017) have observed 413 HII regions in M33 with MMT and analyzed the detail temperatures and oxygen abundances distributions of M33. Sanders et al. (2012) have studied the metallicity profile of M31 based on the observation by the Mosaic Camera of the Mayall telescope and investigated the Hα luminosity function of M31. Sanders et al. (2012) have studied the metallicity profile of M31 based on the spectra of hundreds of HII regions and PNe observed by the Multiple Mirror Telescope (MMT). Lin et al. (2017) have observed 413 HII regions in M33 with MMT and analyzed the detail temperatures and oxygen abundances distributions of M33. Sanders et al. (2012) have studied the metallicity profile of M31 based on the spectra of hundreds of HII regions and PNe observed by the Multiple Mirror Telescope (MMT). Lin et al. (2017) have observed 413 HII regions in M33 with MMT and analyzed the detail temperatures and oxygen abundances distributions of M33. Sanders et al. (2012) have studied the metallicity profile of M31 based on the spectra of hundreds of HII regions and PNe observed by the Multiple Mirror Telescope (MMT). Lin et al. (2017) have observed 413 HII regions in M33 with MMT and analyzed the detail temperatures and oxygen abundances distributions of M33. Sanders et al. (2012) have studied the metallicity profile of M31 based on the spectra of hundreds of HII regions and PNe observed by the Multiple Mirror Telescope (MMT). Lin et al. (2017) have observed 413 HII regions in M33 with MMT and analyzed the detail temperatures and oxygen abundances distributions of M33. Sanders et al. (2012) have studied the metallicity profile of M31 based on the spectra of hundreds of HII regions and PNe observed by the Multiple Mirror Telescope (MMT). Lin et al. (2017) have observed 413 HII regions in M33 with MMT and analyzed the detail temperatures and oxygen abundances distributions of M33.

With 4000 fibers in a field of view of 20 deg2, the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST; Cui et al. 2004) is a powerful facility to archive spectra of millions of detectable objects. As an extension part of the LAMOST Spectroscopic Survey of the Galactic Anti-center (LSS-GAC; Liu et al. 2014, Yuan et al. 2015), the LAMOST M31/M33 survey targets interesting objects in the vicinity fields of M31 and M33, such as the supergiants, PNe (Yuan et al. 2010), HII regions and globular clusters (Chen et al. 2015, 2016), background quasars (Huo et al. 2010, 2013, 2015) and foreground Galactic stars.

In this paper, we will present a systematic search of the Hα emission-line point sources in the vicin-
ity fields of M31 and M33, based on the LAMOST M31/M33 survey data observed during October 2011 and January 2016.

The paper is organized as follows. In Section 2, we briefly introduce the LAMOST observation and
data reduction. Section 3 shows the selection of the Hα emission-line point sources and Section 4 gives
the results. Finally we summarize in Section 5.

2 LAMOST OBSERVATION AND DATA REDUCTION

Objects targeted by LAMOST in the M31 and M33 region include known and candidate objects in
M31 and M33, such as PNe, supergiants, HII regions and globular clusters, known and candidate
background quasars, and foreground Galactic stars. An overview of the target selection of the LAMOST
M31/M33 survey can be referred to Yuan et al. (2015). The LAMOST M31/M33 survey are targeted
by LAMOST telescope from September to January of the next year in each observational season. The
typical total exposure time, depending on the weather conditions, are 600 – 1200 s, 1200 – 1800 s and
1800 – 2400 s for bright (B), medium (M) and faint (F) plates, respectively. For most plates, the seeing
varies between 3 and 4 arcsec, with a typical value of about 3.5 arcsec (Yuan et al., 2015). This work is based on spectra observed by LAMOST during September 2011 and January 2016. In total, 1,114,164 spectra have been collected by the LAMOST M31/M33 survey. Raw data was re-
duced by the LAMOST two-dimensional (2D) pipeline (Luo et al., 2015), including procedures of bias
subtraction, cosmic ray removal, 1D spectral extraction, flat field correction, wavelength calibration and
sky subtraction. The LAMOST spectra are separately recorded in blue (3700 – 5900 Å) and red (5700 –
9000 Å) arms. The blue and red spectra are processed by the 2D pipeline independently and combined
together after the flux calibration, which is processed by an algorithm specifically designed for the LSS-
GAC survey (Xiang et al., 2015). The final combined 1D spectra are then adopted to search for the Hα
emission-line objects and to obtain their properties in this work.

3 SELECTIONS OF Hα EMISSION-LINE POINT SOURCES

We first select objects with spectra that have Hα emission-line by the criteria of signal-to-noise ratio in
the wavelength of 6563 Å larger than 5. This yields a sample of 23,976 Hα emission-line candidates.
Their Hα line profiles are then fitted by Gaussian functions and checked by naked eyes. Any bad spec-
trum that has poor flat-fielding or sky subtraction is then excluded. As a result, this yields 4,448 unique
objects as Hα line emission-line sources. Fig. 1 shows an example of the Gaussian fitting of the Hα emission line for an example object.

In the current work, we are only interested in the Hα emission-line point sources. To exclude the extended sources such as the background galaxies and dwarf galaxies from our sample, we adopt the images and photometric catalogue of the Panoramic Survey Telescope and Rapid Response System-1 (Pan-STARRS 1; Kaiser et al. 2002, 2010). 795 candidates that are flagged as extended sources in the Pan-STARRS 1 catalogue are first excluded in our sample. The Pan-STARRS 1 r-band images of all the remaining objects are visually examined to make sure that all sources in our sample are point sources and free from any contaminators.

There are usually two to three singular explosions for each LAMOST observation. Finally, we have visually examined the singular exposure spectra of the remaining sources and remove objects with fake Hα emission line which appear in only one of those singular explosion spectra. As a result, we obtain 3,305 unique Hα emission-line point sources as our final sample.

4 RESULTS

Our catalogue is available in electronic form in the online version of this manuscript. Table 1 describes the data format of the catalogue. Each row of the catalogue contains the ID, name, coordinates and LAMOST observational information, such as the Plate ID, Spectrograph ID, Fiber ID, observed MJD and the object type tagged in the input catalogue, of the catalogued objects. Multiple observations of the same object are listed together with the same ID and object name. Fig. 2 shows the spatial distribution of all the catalogued Hα emission-line point sources in the vicinity fields of M 31 and M 33 in the ξ–η plane. Here ξ and η are respectively the right ascension and declination offsets relative to the optical center of M 31.

For all the catalogued objects, we have made Gaussian fits to their Hα emission lines. If there are other prominent emission lines such as Hβ, [O III] λ4959, [O III] λ5007, [N II] λ6548, [N II] λ6583, [S II] λ6717 and [S II] λ6731 lines in the spectra, the Gaussian profile fits are also applied to these lines. Some of the emission lines (e.g. Hα and [N II] λ6583 lines) locate in narrow wavelength ranges. In those cases, the spectra are fitted by multiple Gaussian profiles, with one Gaussian component corresponding to one emission line. The center wavelength and integrated area of the Gaussian profiles define the radial
### Table 1 Description of the Catalogue.

| Column | Name                  | Description                                                                 |
|--------|-----------------------|-----------------------------------------------------------------------------|
| 1      | ID                    | Object ID                                                                   |
| 2      | name                  | Object name                                                                 |
| 3      | RA                    | Right Ascension (J2000)                                                    |
| 4      | Dec                   | Declination (J2000)                                                        |
| 5      | plate                 | LAMOST Plate ID                                                             |
| 6      | spid                  | LAMOST Spectrograph ID                                                      |
| 7      | fbid                  | LAMOST Fiber ID                                                             |
| 8      | mjd                   | Observed MJD                                                                |
| 9      | objtype               | Object type tagged in the input catalogue                                   |
| 10     | Vha                   | Radial velocity estimated from Hα line                                      |
| 11     | Vhaerr                | Uncertainty of radial velocity estimated from Hα line                       |
| 12     | fluxha                | Flux of Hα line                                                             |
| 13     | fluxhaerr             | Uncertainty of flux of Hα line                                              |
| 14     | Vhb                   | Radial velocity estimated from Hβ line                                      |
| 15     | Vhberr                | Uncertainty of radial velocity estimated from Hβ line                       |
| 16     | fluxhb                | Flux of Hβ line                                                             |
| 17     | fluxhberr             | Uncertainty of flux of Hβ line                                              |
| 18     | V4959                 | Radial velocity estimated from [O III] λ4959 line                           |
| 19     | V4959err              | Uncertainty of radial velocity estimated from [O III] λ4959 line            |
| 20     | flux4959              | Flux of [O III] λ4959 line                                                  |
| 21     | flux4959err           | Uncertainty of flux of [O III] λ4959 line                                   |
| 22     | V5007                 | Radial velocity estimated from [O III] λ5007 line                           |
| 23     | V5007err              | Uncertainty of radial velocity estimated from [O III] λ5007 line            |
| 24     | flux5007              | Flux of [O III] λ5007 line                                                  |
| 25     | flux5007err           | Uncertainty of flux of [O III] λ5007 line                                   |
| 26     | V6548                 | Radial velocity estimated from [N II] λ6548 line                            |
| 27     | V6548err              | Uncertainty of radial velocity estimated from [N II] λ6548 line             |
| 28     | flux6548              | Flux of [N II] λ6548 line                                                  |
| 29     | flux6548err           | Uncertainty of flux of [N II] λ6548 line                                    |
| 30     | V6583                 | Radial velocity estimated from [N II] λ6583 line                            |
| 31     | V6583err              | Uncertainty of radial velocity estimated from [N II] λ6583 line             |
| 32     | flux6583              | Flux of [N II] λ6583 line                                                  |
| 33     | flux6583err           | Uncertainty of flux of [N II] λ6583 line                                    |
| 34     | V6717                 | Radial velocity estimated from [S II] λ6717 line                            |
| 35     | V6717err              | Uncertainty of radial velocity estimated from [S II] λ6717 line            |
| 36     | flux6717              | Flux of [S II] λ6717 line                                                  |
| 37     | flux6717err           | Uncertainty of flux of [S II] λ6717 line                                    |
| 38     | V6731                 | Radial velocity estimated from [S II] λ6731 line                            |
| 39     | V6731err              | Uncertainty of radial velocity estimated from [S II] λ6731 line            |
| 40     | flux6731              | Flux of [S II] λ6731 line                                                  |
| 41     | flux6731err           | Uncertainty of flux of [S II] λ6731 line                                    |
| 42     | type                  | Object classification of this work                                          |
| 43     |                      |                                                                             |

### Table 2 Summary of the Catalogue

| Type                  | Number |
|-----------------------|--------|
| Emission stars        | New symbiotic star candidate 1 |
|                       | Others (M dwarfs and B[e] stars, etc.) 1486 |
| Emission Nebulae      | Literature PNe 353 |
|                       | New PN candidates 24 |
|                       | Literature H ii regions 64 |
|                       | New H ii region candidates 19 |
|                       | Literature SNRs 10 |
|                       | New SNR candidates 10 |
|                       | Objects with [O III] λ5007 flux < 3 52 |
| Others                | Galaxies and unknown objects 1286 |
velocities and fluxes of the corresponding lines. The resulted properties such as the radial velocity and
flux of the Hα and seven other prominent emission lines (Hβ, [O III] λ4959, [O III] λ5007, [N II] λ6548, [N II] λ6583, [S II] λ6717 and [S II] λ6731) are also listed in our catalogue.

There are 745 duplicate observations for our catalogued objects. In Fig 3 we show the distribution
of the differences of radial velocities from the Hα line deduced from the duplicate observations. The
rms of the differences is about 15 km s⁻¹, which indicate a internal uncertainty of about 10 km s⁻¹ for
the Hα line radial velocities.

Our Hα emission-line point source catalogue consists of objects of different types, including the
emission-line object such as PNe, H II regions and supernovae remnants (SNRs) in M 31 and M 33 and
the Galactic emission-line stars. We cross-match our sample with the SIMBAD Astronomical Database
and find 575 of them been classified, including 213 PNe, 161 emission-line stars and some other types of
objects such as H II regions and SNRs. However, as some of the SIMBAD sources are identified by only
photometric data. Their classification would be incorrect. In the current work, we will provide new clas-
sifications to the catalogued objects based on information of the LAMOST spectroscopic observations.
The new classifications are also listed in the catalogue and a summary is given in Table 2.

4.1 Emission-Line Stars

Based on their LAMOST spectra, the catalogued objects can be roughly divided into two groups, one
group of objects with significant continuum spectrum and the other group without. There are 1,487
objects in our catalogue belonging to the first group. Most of them have spectra of typical stars and have
only the Hα emission lines. We classify them as emission-line stars in the current work. Most of the
emission-line stars are M dwarfs displaying strong TiO bands. There are also several B[e] stars, which
are B-type main-sequence sub-giant or giant stars with prominent Balmer emission, and some novae.
Fig. 3 Histogram of the differences of radial velocities from Hα line deduced from duplicate observations of the same targets. A Gaussian fit to the distribution is overplotted, with the number of objects with duplicate observations, and the mean and dispersion of the Gaussian marked.

One of our catalogued object, LAMOST J004316.72+412226.3, has a spectrum that is very likely to be a symbiotic star. Symbiotic stars are interacting binaries which usually contain a white dwarf and a red giant (Mikołajewska et al., 2014). The spectrum of a symbiotic star usually presents both the feature of a late-type M giant and strong emission lines such as the Balmer H I lines and the [O III] λ5007 forbidden lines. The possible symbiotic star LAMOST J004316.72+412226.3 we find in the current work was classified as a PN in Halliday et al. (2006). Its LAMOST spectrum is displayed in Fig. 4. The spectrum shows typical features of M stars in the red band and hot stars in the blue band. The emission lines of Hα and [O III] λ5007 lines are significant. However, due to the low resolution and limited signal-to-noise ratio of the LAMOST spectrum, follow up observations of this object are needed for any further confirmation.

4.2 Emission-Line Nebulae

In our catalogue, there are 532 objects which display no obvious continuum spectra but have abundant emission lines. They are possible PNe, H II regions, and SNRs.

To exclude the contamination of early type stars, in the current work, we classify only the sources with strong emission of [O III] λ5007 line. These are objects of high electron excitation states, i.e. PNe, H II regions and SNRs. In the current work, we have selected 480 sources with [O III] λ5007 fluxes greater than 3. To distinguish the PNe, H II regions and SNRs from each others, we adopt the commonly used “Baldwin, Phillips & Terlevich” (BPT) and “Sabbadin, Minello & Biancini” (SMB) diagrams. The BPT diagram, which demonstrate how PNe can be distinguished from H II regions on the basis of their [O III] λ5007/Hβ (noted as ‘O3’) and ([N II] λλ6548 + 6583)/Hα (noted as ‘N2’) flux ratios (Baldwin et al., 1981), is then adopted to classify the PNe and H II region candidates in our catalogue. Comparing to PN and H II region, the sulfur in SNR is usually found in a wide range of ionization states and the nitrogen emission line of SNR is sensitive to the presence of its radiative shock. We thus adopt the SMB diagram which separate the SNRs from PNe and H II regions by Hα/([N II] λλ6548 + 6583) (noted as ‘n2’) and Hα/([S II] λλ6717 + 6731) (noted as ‘s2’) flux ratios (Sabbadin et al., 1977; Canto, 1981 and Riesgo & López, 2006). Fig. 5 shows the BPT and SMB diagrams of our catalogued emission-line
nebulae with strong emission lines of \([\text{O III}] \lambda5007\). As a result, we have identified 377 likely PNe, 83 possible \(\text{H II}\) regions and 20 SNRs candidates in our catalogue.

### 4.2.1 Planetary Nebulae

The curve \(\text{O3} > 0.61/(\text{N2} - 0.47) + 1.0\) \cite{Sanders2012} separates the PNe and \(\text{H II}\) regions nicely (Fig. 5). It is adopted in the current work to select the PNe and we have identified 377 PN candidates in our catalogue, including 353 known PNe from the literature and 24 new discoveries. The spectrum of an example PN candidate is shown in Fig. 6. The spatial distribution of all the PN candidates is shown in Fig. 7. Most of the PN candidates are distributed in the disk regions of \(\text{M 31}\) and \(\text{M 33}\). However, some of the PN candidates, especially those newly discovered ones, locate in the halo regions of \(\text{M 31}\) and \(\text{M 33}\). They are valuable for us to study the chemistry and kinematics of the halos of \(\text{M 31}\) and \(\text{M 33}\) as well as streams in the halos.

### 4.2.2 \(\text{H II}\) Regions

From the BPT diagram, we have identified 83 \(\text{H II}\) region candidates in our catalogue, including 64 known objects from the literature and 19 new identifications. The LAMOST spectrum of an example \(\text{H II}\) region candidate is also shown in Fig. 6 and the spatial distribution of all the catalogued \(\text{H II}\) region candidates is shown in Fig. 8.

### 4.2.3 Supernovae Remnants

Following the work of Frew et al.\cite{Frew2010}, we adopt criteria: \(0.6 \log s^2 - 0.08 < \log n^2 < 1.8 \log s^2 + 0.16\) and \(\log n^2 < 0.3\) to select the SNRs candidates (Fig. 5). As a result, we have identified 20 SNRs candidates in the current work, including 10 known ones from literature and 10 new discoveries. Their spatial distribution is also shown in Fig. 8.
Fig. 5 The BPT (left) and SMB (right) diagrams of our catalogued emission-line nebulae with strong [O III] λ5007 emission (grey dots). Known PNe, H II regions and SNRs are plotted as pink, blue and green dots, respectively. The red line in the left panel marks the line we adopted to separate PNe and H II regions while those in the right panel are the criterions we adopted to select the SNR candidates (see text for details).

5 SUMMARY

Based on the spectroscopic data from LAMOST M 31/M 33 survey during September, 2011 and June, 2016, we have selected 3,305 Hα emission-line point sources in the vicinity of M 31 and M 33. We have calculated radial velocities and fluxes of Hα line and those quantities of other 7 major emission lines (Hβ, [O III] λ4959, [O III] λ5007, [N II] λ6548, [N II] λ6583, [S II] λ6717 and [S II] λ6731) of all these catalogued sources from their LAMOST spectra by Gaussian profile fitting method. In our catalogue, we have identified 1487 emission-line stars, including 1 new symbiotic star candidate, 532 emission-line nebulae, including 24 new PN candidates, 19 new H II regions candidates and 10 new SNRs candidates, and 1286 unknown objects. Our catalogue is available in electronic form in the online version of this manuscript. It will serve as an ideal starting point to study the chemistry properties and kinematics of the M 31.

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Fig. 6  LAMOST spectra of a PN candidate LAMOST J004936.62+375022.8 (upper panel) and a H II region candidate LAMOST J003947.69+402059.1 (bottom panel). Vertical lines with different colors mark the positions of the different emission lines.

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**Fig. 7** The spatial distribution of the new PN candidates (blue dots) and known PNe from SIMBAD (orange dots) in our catalogue. Red star symbols mark the center of the M31 and M33 and the grey ellipse the M31 disk region with a semi-major radius of a semi-major radius of 95.3 arcmin. The blue circle shows the region with a projected distance of 50 kpc to the M31 center.

**Fig. 8** Similar as Fig. 7 but for H II regions and SNRs. Known and newly identified candidate H II regions, as well as known and new SNRs candidates are plotted with brown, blue grey and green dots, respectively.

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