Mapping the emission line strengths and kinematics of supernova remnant S147 with extensive LAMOST spectroscopic observations

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Abstract We present extensive spectroscopic observations of supernova remnant (SNR) S147 collected with the Large sky Area Multi-Object fiber Spectroscopic Telescope (LAMOST). The spectra were carefully sky-subtracted taking into account the complex filamentary structure of S147. We have utilized all available LAMOST spectra toward S147, including sky and stellar spectra. By measuring the prominent optical emission lines including H\textalpha, [N\textsc{ii}] \lambda 6584 and [S\textsc{ii}] \lambda\lambda 6717, 6731, we present maps of radial velocity and line intensity ratio covering the whole nebula of S147 with unprecedented detail. The maps spatially correlate well with the complex filamentary structure of S147. For the central 2° of S147, the radial velocity varies from \(-100\) to \(100\) km s\textsuperscript{-1} and has peaks between \(\sim 0\) and \(10\) km s\textsuperscript{-1}. The intensity ratios of H\textalpha/[S\textsc{ii}] \lambda\lambda 6717, 6731, [S\textsc{ii}] \lambda 6717/\lambda 6731 and H\textalpha/[N\textsc{ii}] \lambda 6584 peak at about 0.77, 1.35 and 1.48, respectively, with a scatter of 0.17, 0.19 and 0.37, respectively. The intensity ratios are consistent with the literature values. However, the range of variations of line intensity ratios estimated here, which are representative of the whole nebula, is larger than previously estimated.

Key words: ISM: supernova remnants — ISM: kinematics and dynamics — ISM: general

1 INTRODUCTION

Supernova remnants (SNRs) are interesting objects to study for a number of reasons. They provide insights into the mechanisms of supernova explosions and are possible sources of Galactic cosmic rays. Moreover, SNRs probe the immediate surroundings of supernovae, which are shaped by their progenitors. Currently 294 Galactic SNRs (Green 2014) have been discovered. A great majority (\(\sim 79\%\)) of the known Galactic SNRs is believed to be relatively old (with ages greater than \(10^3\) years and radii larger than \(\sim 5\) pc) and represents evolved objects in either the adiabatic or early radiative stages of their evolutionary development (Woltjer 1972). These cases generally show characteristic shell structures (Fesen et al. 1985). About 30\% of Galactic SNRs are known to have optical emission associated with their nonthermal radio emission. For old remnants, the optical emission arises from cooling of shocked interstellar cloud material following the passage of the remnant’s blast waves as they expand outward into the ambient medium. Optical spectra of filaments of evolved SNRs show strong emission includ-
ing that of Hα, [O II] 3726,3729, [O III] 4959,5007, [N II] 6548,6584 and [S II] 6717,6731. The line intensity ratios have important physical implications, such as the Hα/[S II] ratio that can be used to distinguish shocked nebulae from photoionized nebulae; the [S II] 6717/[S II] ratio is electron density sensitive; the Hα/[N II] ratio is widely used tool for investigating nitrogen-to-hydrogen abundance variations among SNRs. Thus, it is important to obtain complete sampling of the optical line emissions in SNRs. Although several evolved remnants have well studied morphology in the optical, only a limited amount of spectroscopic data are available for those faint optical remnants, especially for those with large angular sizes including SNR S147.

S147 (also named G180.0−1.7) is an optically faint, highly filamentary shell-type SNR in the direction of the Galactic anticenter. It was first identified as an SNR candidate by Minkowski (1958). S147 is now believed to be one of the most evolved SNRs (with an estimated age \( \sim 10^5 \) yr) in the Galaxy. Except for the spurs associated with an SNR, S147 has a shell-like structure with diameter \( \sim 200' \). In the optical bands, the shell structure is dominated by filamentary Hα emission. The emission is bright at the northern and southern edges but is concentrated mainly in the southern parts (Dincel et al. 2015). Despite its old age, it preserves its spherical symmetry well, except for the blowout regions in the east and west. The optical and radio shell morphologies are well defined (Minkowski 1958; Fuerst & Reich 1986) and coincide with each other.

Figure 1 shows images of S147 in different bands. Although no X-ray emission has been detected by EXOSAT (Sauvageot et al. 1990), Sun et al. (1996) reported unambiguous X-ray emission from S147 based on data from the ROSAT All Sky Survey (RASS, Voges et al. 1999). Chen et al. (2017) claimed that the X-ray emission and dust extinction are anti-correlated. A spatially extended gamma-ray source detected in the energy range 0.2–10 GeV is found to coincide with S147. The gamma-ray emission exhibits possible spatial correlation with the prominent Hα filaments of S147 (Katsuta et al. 2012).

A compact object, the radio pulsar J0538+2817 (Anderson et al. 1996) which is located 40' west of the center of S147, is believed to be associated with S147. An early type (B0.5V) runaway star, HD 37424, has also been found inside S147, and is believed to be the pre-supernova binary companion to the progenitor of the pulsar and the SNR (Dincel et al. 2015). The distance estimated for S147 in the literature spans a wide range, 0.6–1.9 kpc, depending on the methods used (Dincel et al. 2015). The surface brightness and distance (\( \Sigma-D \)) relation typically yield a distance of \( \sim 1 \) kpc from several studies (Clark & Caswell 1976; Kundu et al. 1980; Guseinov et al. 2003). The interstellar reddening toward S147 suggests a smaller distance of 0.8 kpc (Fesen et al. 1985). On the other hand, distances derived from the parallax of the pulsar are significantly larger, ranging between 1.3–1.5 kpc (Chatterjee et al. 2009; Ng et al. 2007). A recent study yields distance \( d = 1.33^{+0.10}_{-0.11} \) kpc and extinction \( A_V = 1.28 \pm 0.06 \) mag (Dincel et al. 2015). Finally, from a dust extinction analysis based on data from the Xuyi Schmidt Telescope Photometric Survey of the Galactic Anti-Center (XSTPS-GAC; Liu et al. 2014; Zhang et al. 2014), Chen et al. (2017) obtain a new measurement of distance to S147, \( d = 1.22 \pm 0.21 \) kpc. The expansion velocity estimated for the S147 shell ranges between 80–120 km s\(^{-1}\) (Kirshner & Arnold 1979; Phillips et al. 1981).

Previous optical spectrophotometric observations of S147 (Kirshner & Arnold 1979; Fesen et al. 1985) obtain only dozens of spectra, covering a small portion of the extremely large and faint SNR S147. The observations focused on several bright filaments. S147 consists of numerous filaments embedded in diffuse emission. The two components (i.e., bright filaments and diffuse emission) have quite different physical properties. It is thus important to sample fully the whole extent of S147 in order to obtain a comprehensive understanding of an evolved SNR such as S147.

The Large sky Area Multi-Object fiber Spectroscopic Telescope (LAMOST) is a quasi-meridian reflecting Schmidt telescope with \( \sim 4\) m effective aperture and a field of view of 5° diameter (Cui et al. 2012). It is located at the Xinglong Station of National Astronomical Observatories, Chinese Academy of Sciences. Being a dedicated survey telescope, LAMOST acquires spectra with 4000 fibers, targeting interesting celestial objects including sky background and calibration sources in one single exposure with 16 fiber-fed spectrographs, each accommodating 250 fibers. The spectra cover the entire optical wavelength range (\( \sim 3700–9000 \) Å) at a resolving power \( R \sim 1800 \). Since September 2012, LAMOST has been carrying...
Fig. 1 Multi-band images of SNR S147. The upper panels show optical images in $H_\alpha$ (left) from the IPHAS survey (Drew et al. 2005) and in $R$-band from the DSS (right). The middle panels display radio images at 11 cm (2639 MHz; left) obtained with the Effelsberg 100-m and the Urumqi 25-m telescopes respectively (Xiao et al. 2008). The bottom panels depict high-frequency radio maps at 31 GHz (left) and 44 GHz (right) obtained with the Wilkinson Microwave Anisotropy Probe (WMAP) (Xiao et al. 2008). The light green cross and dot in each panel mark respectively the geometrical center of S147 and the position of pulsar J0538+2817, probably associated with S147.

out five-year Regular Surveys. Before that there was a one-year Pilot Survey preceded by a two-year commissioning phase. The LAMOST Regular Surveys consist of two components (Zhao et al. 2012): the LAMOST Extra-Galactic Survey of Galaxies (LEGAS) that aims at studying the large scale structure of the Universe, and the LAMOST Experiment for Galactic Understanding and Exploration (LEGUE) with the goal of obtaining millions of stellar spectra in order to study the structure and evolution of the Milky Way (Deng et al. 2012).

LEGUE has three sub-components: the spheroid, anticenter and disc surveys. The LAMOST Spectroscopic Survey of the Galactic Anti-Center (LSS-GAC; Liu et al. 2014; Yuan et al. 2015; Xiang et al. 2017) aims to survey a significant volume of the Galactic thin/thick discs and halo for a contiguous sky area of over 3400 deg$^2$ centered on the Galactic anticenter ($|b| \leq 30^\circ$, $150^\circ \leq l \leq 210^\circ$), down to a limiting magnitude of $r \sim 17.8$ mag (to 18.5 mag for limited fields). S147 is located within the LSS-GAC footprint. A large number of foreground and background stars toward S147 have been targeted by LAMOST accidentally, some several times. S147 has a large diameter and contains many filaments. It would be extremely time consuming if one attempted to obtain
spectra covering its full spatial extent using regular telescopes. The wide field of view, multi-fiber survey telescope LAMOST thus serves as a perfect tool for mapping the details of this extremely extended, evolved SNR. It provides us with a great opportunity to study the global properties of S147 with unprecedented detail for the first time.

In this paper, we focus on the analysis of LAMOST optical spectra associated with S147. In particular, we concentrate on the kinematic properties revealed by strong emission lines including Hα, [N ii] λλ 6548,6584 and [S ii] λλ 6717,6731. In Section 2 we describe the observation and data reduction. In Section 3 we present parameter determinations and result analysis. Section 4 summarizes our findings.

2 OBSERVATION AND DATA REDUCTION

2.1 Observation

LAMOST Data Release 2 (DR2) includes data from 1934 plates collected by June 2014, among them 401 plates are from the Pilot Surveys (from October 2011 to June 2012), 808 plates from the first year Regular Surveys (from September 2012 to June 2013) and 725 plates from the second year Regular Surveys (from September 2013 to June 2014). Totally, the DR2 general catalog contains 4 132 782 spectra, including 3 779 674 stars, 37 665 galaxies, 8633 QSOs and 306 810 unknown objects. LAMOST DR2 was released internally in December 2014 and publicly in June 2016.

Being a large-size SNR in the direction of the Galactic anticenter, many foreground and background stars in the vicinity region of S147 have been targeted, some several times by LAMOST since 2011. There are 50 LAMOST plates overlapping with (or very close to) S147. Figure 2 plots the positions of these 50 plates included in LAMOST DR2, overlaid with an Hα image from the IPHAS survey (Drew et al. 2005).

Among the 50 LAMOST plates, 16 have a center of field of view within 3.55° of the geometric center of S147 (10 B plates, and 6 M plates). Of those 16 plates, 9 are from the Pilot Surveys and 7 from the first year Regular Surveys. The other 34 plates have centers of field of view between 3.55° and 4.54° from the geometric center of S147 (5 VB plates, 26 B plates, 16 M plates and 3 F plates). Among those 50 plates, 28 are from the Pilot Surveys, 18 from the first year Regular Surveys and 4 from the second year Regular Surveys.

2.2 Data Reduction

2.2.1 Overview

LAMOST raw spectra are processed with the LAMOST two-dimensional (2D) pipeline (Luo et al. 2012, 2015), including dark and bias subtractions, cosmic ray removal, one-dimensional (1D) spectral extraction, flat-field correction, wavelength calibration, sky subtraction, merging sub-exposures, and finally, splicing the sub-spectra from the blue- and red-arm of the spectrograph. Xiang et al. (2015a) develop an iterative algorithm for the flux calibration in order to overcome the effect of often heavy interstellar reddening that hinders the selection of suitable standard stars (F stars). For a given spectrograph, the spectra are first flux-calibrated using the nominal spectral response curve (SRC) and the initial stellar atmospheric parameters are derived with the LAMOST Stellar Parameter Pipeline at Peking University (LSP3; Xiang et al. 2015b). Then based on those initial estimates of stellar parameters, stars with effective temperature \( T_{\text{eff}} \) between 5750 and 6750 K (mostly of F spectral type) are selected as the flux-calibration standard stars and used to deduce an updated SRC after being corrected for interstellar reddening, derived by comparing the observed and synthetic photometric colors, assuming the Fitzpatrick (1999) extinction law for a total to selective extinction ratio \( R_V = 3.1 \). The new SRC is then used to flux-calibrate the spectra and the stellar parameters are updated accordingly from the recalibrated spectra. The above process is repeated until a convergence is achieved. Usually more than four standard stars per spectrograph can be identified and selected for the majority of LSS-GAC plates. In cases where not enough standard stars can be selected for a given spectrograph (plate), the SRC(s) deduced from other plates, usually collected on the same night, are used to do the calibration. A comparison of spectra obtained at different epochs for duplicate targets indicates that the relative flux calibration has achieved an accuracy of about 10 percent for spectra with a signal to noise ratio (S/N) per pixel higher than 30 at 4650 Å (Xiang et al. 2015a).
2.2.2 Data toward S147

In total, there are 19,736 spectra (including those from the sky fibers) within 2° of the geometric center of S147, among which 4,667 spectra (4,349 unique stars) have available LSP3 stellar atmospheric parameters. Figure 3 shows the histogram distributions of spectral S/N in the red (7,450 Å) regions of the 19,736 spectra within 2° of S147.

2.2.3 Sky subtraction

For each LAMOST plate, ∼10–15 percent of the fibers are assigned as object-free sky fibers pointing toward areas of blank sky for modeling the night sky background. A method of B-spline fitting (Stoughton et al. 2002; Luo et al. 2015) is applied to make a supersky for each sub-exposure of a spectrograph and then principal component analysis (PCA) is used to recorrect the supersky. The fiber assignment strategy works well for fields at high Galactic latitudes, yielding results comparable to those of the SDSS survey. However, for sky areas near the Galactic plane, such as of S147 where the sky is plagued by diffuse and highly filamentary nebular emission, this strategy fails to build a supersky with adequate accuracy. In the current work, we develop a new method for sky subtraction, which is described below.

Overall S147 has a quite regular and nearly spherical shape, with a diameter of ∼3°, smaller than the field of view of LAMOST (5° in diameter). For the individual LAMOST plates taken in the vicinity field of S147, there are always some regions not contaminated by the emission of S147. Thus for those plates, we are able to use the sky fibers positioned at points uncontaminated by...
S147 emission to rebuild the supersky and redo the sky subtraction. This procedure is carried out for the blue- and red-arm spectra separately. The uncontaminated sky spectra from the non-S147 region are selected following the criteria: 1) at least 2° away from the S147 geometric center; 2) not contaminated by S147 emission, i.e., those with a detectable Hα flux (larger than 2σ, for a strict cut) are also excluded. The sky spectra thus selected which satisfy the above criteria are then averaged to construct the so-called “uncontaminated non-S147 supersky.”

LAMOST has 16 spectrographs, each fed by 250 fibers, where 10 to 20 of them are normally assigned as sky fibers. For the individual spectrographs, the “uncontaminated non-S147 supersky” cases are scaled to match each sky spectrum. The scaling procedure includes two steps: scaling by the continuum and by the telluric emission lines. The continuum scaling is carried out first, and then the line scaling. In the current work, intensities of the sky emission lines λ6498, λ6533 in red-arm are used for the line scaling. We then obtain a “new initial supersky” for each of the 16 spectrographs (abnormal sky spectra are excluded during this process). We note that continuum and line scaling works much better for a limited wavelength region than for the whole spectrum. In this paper, we focus only on selected wavelength regions of interest here: 6400–6800 Å in the red that contains Hα, and the [N ii] λλ6548,6584 and [S ii] λλ6717,6731 nebular lines. The sky subtraction is only carried out for the two selected wavelength regions. Once the “new initial supersky” has been obtained, segments of this spectrum are replaced by the “uncontaminated non-S147 supersky” for the following wavelength ranges: 6490–6620 Å and 6695–6750 Å. The supersky spectra thus obtained are then used for the final sky subtraction.

For an uncontaminated spectrograph, sky fibers fall outside the S147 emission region and are thus free of S147 emission. The final adopted supersky differs little from the supersky yielded by the LAMOST 2D pipeline. For uncontaminated spectrographs, the reconstructed new supersky agrees well with the original LAMOST supersky, indicating that the LAMOST default supersky works well for uncontaminated sky regions. For contaminated spectrographs, the differences between our newly adopted supersky and that given by the LAMOST 2D pipeline can be significant, especially for spectral regions affected by prominent nebular emissions such as Hα, [N ii] λλ6548,6584 and [S ii] λλ6717,6731. Our sky subtraction procedure has a typical uncertainty of approximately 10 percent. After the sky subtraction, nebular features, especially Hα, [N ii] λλ6548,6584 and [S ii] λλ6717,6731 lines, become clearly visible.

3 PARAMETER DETERMINATIONS

To investigate the kinematic properties of S147, we determine by Gaussian fitting the radial velocities and line intensities of prominent emission lines including Hα, [N ii] λλ6548,6584 and [S ii] λλ6717,6731. Only nebular lines in the red-arm spectra are analyzed, given that they are much stronger than those in the blue. Usually, the red-arm spectra have a higher S/N than the blue-arm ones.

There are typically ∼300 sky spectra per plate. To utilize as many spectra as possible, all spectra of foreground and background stars in the S147 vicinity field are analyzed as well. A small portion of those stellar spectra have good S/N, allowing stellar parameter determinations. For the remaining ones, because of the low S/N, no stellar parameters are available from LSP3 (as

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**Fig. 3** Histogram distribution of spectral S/N in red parts of the spectra, for the 19736 LAMOST spectra within 2° of S147.
shown in Fig. 3). Since the stellar features may affect the measurements of nebular emission lines of S147, they need to be subtracted before determining the properties of nebular emission lines.

For high quality stellar spectra with available stellar atmospheric parameters determined with LSP3, the subtraction is done using high quality spectra of “paired stars” that have almost the same stellar atmospheric parameters in regions uncontaminated by nebular emission (Yuan et al. 2013). The “paired stars” are selected from the LSS-GAC Value-added Catalogs DR1 (Yuan et al. 2015) following the criteria: (1) located at high Galactic latitudes ($b > 20^\circ$); (2) suffer little from low extinction (ebv$_{sp} < 0.05$ mag, where ebv$_{sp}$ is the $E(B-V)$ derived from the star pair method, see Yuan et al. (2015) for details); (3) have high S/N spectra ($S/N_b > 20$ or $S/N_r > 20$; in a few cases where no matching stars are found, this is relaxed to $S/N_b > 10$ or $S/N_r > 10$, where $S/N_b$ and $S/N_r$ represent the S/N in $b$ and $r$ band respectively); (4) have stellar atmospheric parameters with small uncertainties (effective temperature error $\text{teff}_{\text{err}} < 150$ K, surface gravity error $\log g_{\text{err}} < 0.25$ dex and metallicity error $\text{feh}_{\text{err}} < 0.15$ dex); (5) have stellar atmospheric parameters that differ from the targeted stars by small amounts (specifically, the effective temperature difference $\Delta T_{\text{eff}} < 150$ K, surface gravity difference $\Delta \log g < 0.25$ dex and metallicity difference $\Delta [\text{Fe/H}] < 0.15$ dex). For a given target star, the spectrum of a “paired star” that satisfies all the above criteria and has the smallest value of $d = \frac{\Delta T_{\text{eff}}}{150} + \frac{\Delta \log g}{0.25} + \frac{\Delta [\text{Fe/H}]}{0.15}$ is used to subtract the stellar spectrum from the target spectrum. Figure 4 displays an example of stellar spectrum subtraction.

Most of those low S/N stellar spectra with no stellar atmospheric parameters available from LSP3 are of faint stars. The spectra are thus only marginally affected by stellar features. For those spectra, we have ignored the possible contamination of stellar features and measure directly the properties of nebular emission lines without stellar spectrum subtraction.

Figure 5 shows an example of a low S/N stellar spectrum. Although the (stellar) continuum is quite noisy and has flux close to zero, the nebular emission lines are quite prominent.

We determine radial velocities and intensities of H$\alpha$, [N$\text{II}$] $\lambda$6548,6584 and [S$\text{II}$] $\lambda$6717,6731 nebular emission lines from all available spectra in the vicinity field of S147. Part of the results are given in Table 1. The full table can be found online. Figure 6 depicts example red-arm spectra for several selected filaments.

## 4 DISCUSSION

### 4.1 The Radial Velocity Fields

As shown in Figure 6, the [N$\text{II}$] $\lambda$6548 line is in general rather weak and seen only in a few high quality spec-
Fig. 4 Example of stellar spectrum subtraction. The first row shows the normalized spectrum of a target star with LAMOST spectral ID “2011126-GAC_082N27_M1-3-85” (grey line), and that of the paired-star with ID “20120203-B5596104-6-55” (black line). The second row displays the same two spectra after the continuum level of the paired-star spectrum has been scaled to match that of the target star. The residuals after subtraction (i.e. the spectrum of S147 filament) are depicted in the third row.

Fig. 5 Example of a low S/N stellar spectrum with LAMOST ID “20111024-F5909-13-28” (S/N$_{b} = 1.0476$, S/N$_{r} = 2.8407$). The top and bottom panels show the blue- and red-arm spectra, respectively.

Hα is the strongest nebular line and visible in almost all the spectra. The [N II] λ 6584 line has a typical strength comparable to the [S II] λλ 6717, 6731 lines. The latter three lines have comparable occurrence rates and are often less strong than Hα. For spectra of comparable S/N, the stronger the nebular lines are, the higher the detection rates will be, and vice versa. In the current work, only Hα, [NII] λ 6584 and [SII] λλ 6717, 6731 lines are used to measure the kinematic properties of S147.

Figure 7 displays the radial velocity field of S147 as revealed by the emission lines measured. One can see that radial velocity fields mapped by emission lines exhibit spatial features that are well correlated. The radial velocities of different filaments of S147 exhibit complex structure and variations. Some of the filaments are moving towards us (such as the segment marked by a blue ellipse in Fig. 7), and some are moving away from us (such as the segment marked by a red ellipse in Fig. 7).
Probably due to the projection effects or a direct consequence of the complex structure of the filaments, many segments of filaments of blue- and red-shifted velocities are tangled together. One such example is marked by a green ellipse in Figure 7. The radial velocity fields presented here cover the whole extent of S147 with unprecedented sampling. Figure 8 shows histogram distributions of all derived radial velocities with uncertainties less than 20 km s\(^{-1}\) as determined from various lines for spectra within 2\(\degree\) of the geometric center of S147. The distributions peak between \(\sim 0 - 10\) km s\(^{-1}\).

### 4.2 Maps of Line Intensity Ratios

Figure 9 displays the distributions of line intensity ratio H\(\alpha\)/[N\(\,\)\(\,\)\(\,\)] \(\lambda\) 6584, H\(\alpha\)/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) \(\lambda\) 6717, 6731 and [S\(\,\)\(\,\)\(\,\)] \(\lambda\) 6717/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) 6731. Similar to the distributions of radial velocities (Fig. 7), the line intensity ratios are measured well along prominent H\(\alpha\) filaments.

Figure 10 shows the histogram distributions of the above line intensity ratios, derived from spectra within 2\(\degree\) of the center of S147. The ratios H\(\alpha\)/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) \(\lambda\) 6717, 6731 and [S\(\,\)\(\,\)\(\,\)] \(\lambda\) 6717/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) 6731 peak at \(\sim 0.77\) (dispersion \(\sigma = 0.17\)) and 1.35 (\(\sigma = 0.19\); i.e. close to the low electron density limit), respectively. Our results are consistent with previous measurements (H\(\alpha\)/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) \(\lambda\) 6717, 6731 ranges between 0.7 - 1.08; [S\(\,\)\(\,\)\(\,\)] \(\lambda\) 6717/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) 6731 \(\sim 1.4\)) in the literature (Fesen et al. 1985; Lozinskaia 1976). Since the [N\(\,\)\(\,\)\(\,\)] \(\lambda\) 6548 line is weak and only detected in a very limited sample of spectra, we use only the [N\(\,\)\(\,\)\(\,\)] \(\lambda\) 6584 line to calculate the H\(\alpha\)/[N\(\,\)\(\,\)\(\,\)] ratio, i.e. H\(\alpha\)/[N\(\,\)\(\,\)\(\,\)] \(\lambda\) 6584. The peak value of H\(\alpha\)/[N\(\,\)\(\,\)\(\,\)] \(\lambda\) 6584 is \(\sim 1.48\) (\(\sigma = 0.37\)), again in good agreement with the literature values of \(\sim 1.20 - 1.58\) (D’Odorico & Sabbadin 1977).

Figures 11 and 12 depict example spectra of filaments with high and low line intensity ratios and of strong and weak line intensities, respectively.

Generally SNRs differ from H\(\,\)\(\,\)\(\,\) regions by showing stronger [S\(\,\)\(\,\)\(\,\)] \(\lambda\) \(\lambda\) 6717, 6731 emission. Quantitatively, H\(\alpha\)/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) \(\lambda\) 6717, 6731 < 2.0 for SNRs (Fesen et al. 1985). The middle panels of Figures 9 and 10 demonstrate that in S147, the H\(\alpha\)/[S\(\,\)\(\,\)\(\,\)] \(\lambda\) \(\lambda\) 6717, 6731 ratio has values less than \(\sim 1.4\), consistent with S147 being a typical SNR.
Fig. 7 S147 radial velocity field as revealed by Hα, [N II] λ 6584 and [S II] λλ 6717, 6731 emission lines. The color bar shows the radial velocity values (km s⁻¹). Within 3° of the geometric center of S147, there are in total 3344, 1282, 1707 and 1310 data points in the panels from top left to bottom right, respectively. The blue and red ellipses mark example filaments moving away and towards the observer, respectively. The green ellipse shows an example of blue-/red-shifted filaments tangled together.

Fig. 8 Histogram distributions of radial velocities determined from Hα, [N II] λ 6584 and [S II] λλ 6717, 6731 emission lines for spectra within 2° of the geometric center of S147. Only radial velocity measurements with errors less than 20 km s⁻¹ are included. Mean and standard deviation of the distribution are marked in each panel.
Fig. 9 Similar to Fig. 7, but for line intensity ratios: Hα/[N II] λ6584, Hα/[S II] λλ6717, 6731 and [S II] λ6717/[S II] λ6731 (from top to bottom, respectively). Totally, within 3° of S147, there are 1075, 896 and 1041 data points in the panels from top to bottom, respectively.
It has been suggested that the intensity ratios Hα/[N II] λ 6584, Hα/[S II] λλ 6717, 6731 and [S II] λ 6717/[S II] λ 6731 vary less from region to region of a given SNR than they do among different SNRs (Daltabuit et al. 1976). Based on this, Daltabuit et al. (1976) developed an evolutionary scheme for SNRs in which Hα/[N II] λλ 6548, 6584 and [S II] λ 6717/[S II] λ 6731 vary systematically as a function of the SNR diameter. In addition, the Hα/[N II] λλ 6548, 6584 ratio combined with electron density indicated by the [S II] λ 6717/[S II] λ 6731 ratio has been used to infer the elemental abundance gradients in the Milky Way, M31 and M33 (Fesen et al. 1985; Binette et al. 1982; Dopita et al. 1980; Blair et al. 1981, 1982; Blair & Kirshner 1985). This approach is only valid if the aforementioned line ratio does not vary sig-
significantly for a given SNR. Only very limited filaments of Galactic SNRs have been studied spectroscopically. The extensive data presented in the current work provide an opportunity to investigate the intrinsic variations of line intensity ratios in a given SNR and test the legitimacy of the aforementioned approach.

From Figures 9 and 10, we estimate that the intrinsic dispersions of line ratios amount to be approximately $\pm 14\%$ for $\lambda 6717/\lambda 6731$, $\pm 22\%$ for $\lambda 6748, 6584$, $\lambda 6717, 6731$ and $\pm 25\%$ for $\lambda 6584$. The dispersions are larger than those previously estimated by Fesen et al. (1985) based on only five observations (the mean values of $\lambda 6717, 6731$ and $\lambda 6717/\lambda 6731$ are respectively 1.28, 1.00 and 1.61, with corresponding dispersions of $\pm 11\%$, $\pm 8\%$ and $\pm 12\%$) and those estimated by Dodorico & Sabbadin (1976) based on only six observations (the mean values of $\lambda 6717, 6731$ and $\lambda 6717/\lambda 6731$ are respectively 1.44, 0.79 and 1.35, with corresponding dispersions of $\pm 9\%$, $\pm 10\%$ and $\pm 6\%$). On the other hand, the results presented here are comparable to the dispersions estimated for nine typical SNRs as listed in Table 5 of Fesen et al. (1985). The large intrinsic dispersions of line intensity ratios seen in S147 cast doubt on the viability of using those ratios to infer the evolutionary stage of an SNR or to estimate the Galactic elemental abundance gradient using SNRs (see also Fesen et al. 1985).

Being an electron density diagnostic, the $\lambda 6717/\lambda 6731$ ratio has a mean value of 1.35 for S147, i.e. close to the low density limit of 1.4 (see fig. 6 in Blair & Kirshner (1985) for the $\lambda 6717/\lambda 6731$ ratio as a function of electron density, the electron density becomes lowest when the $\lambda 6717/\lambda 6731$ ratio has a value of 1.4). The result is consistent with typical values found for evolved SNRs (larger than 1.10, thus implying an electron density lower than 300 cm$^{-3}$; Fesen et al. 1985). We estimate that $\lambda 6717/\lambda 6731$ has an intrinsic dispersion of 14% in S147, slightly larger than those found previously by Fesen et al. (1985) and Dodorico & Sabbadin (1976) (12% and 6%, respectively). The result suggests a small range of electron densities and cloud pressures in S147. A relation between electron density and the $\lambda 6717/\lambda 6731$ line ratio has previously been presented by Blair & Kirshner (1985) (see Blair & Kirshner 1985, Fig. 6) assuming a five level atomic model, the collisional strengths of Pradhan (1978) and the transition probabilities of Mendoza & Zeippen (1982). From the plot of Blair & Kirshner (1985), the mean value of the $\lambda 6717/\lambda 6731$ ratio seen in S147, 1.35 along with a standard deviation 0.19, implies an electron density of only $\sim 50$ cm$^{-3}$, with an upper limit of about 200 cm$^{-3}$.

### 4.3 Comparison with Previous Spectroscopic Observations

Kirshner & Arnold (1979) observed 15 positions of S147 (see Table 1 in their paper) and measured their radial velocities. Their figure 1 shows the slit positions used. The exact coordinates of the slit positions are however not given in the paper, so it is hard to make an exact comparison. Referring to their figure 1, we select some of their slit positions that overlap approximately with (or close to) some of the fiber positions measured with LAMOST.

Table 2 compares the radial velocities determined by Kirshner & Arnold (1979) and by us. Although the differences between our measurements and literature values for positions ‘c’ and ‘k’ seem large ($\sim 30$ km s$^{-1}$), we need to remember that systematic uncertainty in radial velocity is 10 km s$^{-1}$ (Luo et al. 2015) and the comparison here is not exact for the spectra obtained in the same position. So finally, we conclude that the agreement is reasonable.

| Position | Radial Velocity (Kirshner & Arnold 1979) | Radial Velocity (here) |
|----------|------------------------------------------|------------------------|
|          | (km s$^{-1}$)                             | (km s$^{-1}$)          |
| c        | $+54\pm 7$                               | $+21\pm 8$            |
| d        | $+4\pm 8$                                | $+1\pm 18$            |
| e        | $-21\pm 9$                               | $-20\pm 6$            |
| h        | $-47\pm 8$                               | $-37\pm 8$            |
| k        | $+33\pm 6$                               | $+66\pm 7$            |
| m        | $-12\pm 8$                               | $-20\pm 5$            |

Fesen et al. (1985) carried out spectroscopic observations of five positions in S147. Two of them are close to the filaments also observed with LAMOST (P2 and P5 in Fig.13).

Table 3 compares the $H\alpha/\lambda 6584$ line intensity ratios as determined by Fesen et al. (1985) and by us for P2 and P5. Because the exact positions of their observations are about 4′ away from our observations, the small differences between the two sets of measurements seem to be acceptable.
Fig. 12 Example spectra of filaments with strong and weak line intensities.

Table 3 Comparison of line intensity ratio measurements with those of Fesen et al. (1985). The second column shows the distances between the positions of measurements of Fesen et al. (1985) and of LAMOST.

| Position | Distance (arcmin) | Hα/[SII] (Fesen et al. 1985) | Hα/[SII] (here) |
|----------|-------------------|-------------------------------|-----------------|
| P2       | 3.5               | 0.90                          | 0.87            |
| P5       | 4.0               | 0.93                          | 0.68            |

5 SUMMARY

We have analyzed all spectra available in LAMOST DR2 collected in the vicinity field of SNR S147. The spectra are carefully sky subtracted. Both the spectra of the sky background and of foreground and background stars are used. For high-quality stellar spectra with atmospheric parameters determined, the underlying stellar features are subtracted before measuring the nebular emission line properties. For stellar spectra with low S/N and with no stellar atmospheric parameters determined, the spectra are directly used to measure the nebular line properties.

By measuring the prominent emission lines Hα, [N II] λ 6584 and [S II] λλ 6717, 6731, we obtain fundamental kinematic properties of S147, including maps of radial velocity and intensity ratio with exquisite detail. As it is not a dedicated filamentary survey of LAMOST in the S147 region, the number of filamentary spectra is very low compared with the total number of spectra in
this region, but this is still the first time such a large SNR has been fully mapped spectroscopically.

The radial velocity distribution peaks \( \sim 0-10 \text{ km s}^{-1} \). The intensity ratios \( \text{H}\alpha/\text{S} \lambda\lambda 6717,6731 \) and \( \text{[S ii]} \lambda\lambda 6717/\text{S} \lambda\lambda 6731 \) peak respectively at \( \sim 0.77 \) (\( \sigma = 0.17 \)) and 1.35 (\( \sigma = 0.19 \)), consistent with previous determinations in the literature. The \( \text{H}\alpha/\text{N} \lambda\lambda 6584 \) ratios peak at \( \sim 1.48 \) (\( \sigma = 0.37 \)) and agree well with the literature value (\( \sim 1.20 - 1.58 \)). The intrinsic dispersions of line intensity ratios estimated here are larger than previous estimates in the literature, based on observations of only a few filaments.

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