The revised distance of supernova remnant G15.4+0.1

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Abstract We measure the distance to the supernova remnant G15.4+0.1 which is likely associated with TeV source HESS J1818–154. We build the neutral hydrogen (H\textsc{i}) absorption and $^{13}$CO spectra for supernova remnant G15.4+0.1 by employing data from the Southern Galactic Plane Survey (SGPS) and the H\textsc{i}/OH/Recombination line survey (THOR). The maximum absorption velocity of about 140 km s\textsuperscript{-1} constrains the lower limit of its distance to about 8.0 kpc. Further, the fact that the H\textsc{i} emission feature at about 95 km s\textsuperscript{-1} seems to have no corresponding absorption suggests that G15.4+0.1 likely has an upper limit for distance of about 10.5 kpc. The $^{13}$CO spectrum for the remnant supports our measurement. The new distance provides revised parameters on its associated pulsar wind nebula and TeV source.

Key words: ISM: supernova remnants — methods: data analysis — stars: distances

1 INTRODUCTION

The supernova remnant (SNR) G15.4+0.2, also called G15.42+0.18 (G15 hereafter), has a break-out morphology toward its south and a northern shell with a radius of about 6\arcmin in 1420 MHz. The spectral index of G15 is $-0.62 \pm 0.03$ from 330 to 4800 MHz (Supan et al. 2015; Sun et al. 2011) with its peak flux density of 5.6 Jy at 1 GHz. G15 has a morphological correspondence with the TeV $\gamma$-ray source HESS J1818–154 (Adrián-Martínez et al. 2011). The high energy radiation possibly originates from a pulsar wind nebula (PWN) although the pulsar has not been detected. Multiwavelength studies have been performed to explore their properties (e.g. H. E. S. S. Collaboration et al. 2014; Castelletti et al. 2013).

Distance is a key to further study this TeV SNR. A near distance for the remnant G15 was suggested by Castelletti et al. (2013) by analyzing a noisy H\textsc{i} absorption spectrum of the remnant. We make a further effort to obtain a reliable distance to it by taking advantage of data from the newly-released H\textsc{i}/OH/Recombination line survey (THOR, Beuther et al. 2016), as well as the archive Southern Galactic Plane Survey (SGPS, McClure-Griffiths et al. 2005), the Very Large Array Galactic Plane Survey (VGPS, Stil et al. 2006) and the Galactic Ring Survey (GRS, Jackson et al. 2006).

The SGPS has a resolution of 100\arcsec and a sensitivity of less than 1 mJy beam\textsuperscript{-1}, and was observed by the Australia Telescope Compact Array (ATCA) and Parkes telescopes. The SGPS survey has a reliable absolute flux scale by including the Parkes data. The continuum data of SGPS near the G15 region are currently not available. The THOR survey observed H\textsc{i}, four OH and 19 H\textalpha recombination lines, and the L-band continuum covering the northern Galactic plane ($15^\circ < l < 67^\circ$ and $|b| < 1^\circ$). The THOR data have an angular resolution of about 20\arcsec. We convert the unit of Jy beam\textsuperscript{-1} in the THOR data to Kelvin (K) using factors of 1536.20 for the data cube. The absolute scale of the surface brightness in the THOR data is not reliable due to lacking a zero baseline. However, the relative scale is good enough for us to do H\textsc{i} absorption analysis. In addition, we adopt the $^{13}$CO data from the GRS to confirm the reality of the
absorption peaks, because $^{13}$CO is a tracer of cold and dense H$_2$ molecular clouds.

2 SPECTRAL ANALYSIS

We use well-tested methods in order to build as reliable of an H$_I$ absorption spectrum for G15 as possible (Tian et al. 2007; Tian & Leahy 2011; Zhu et al. 2013).

We improve how the absorption spectrum is extracted by using two steps. We choose a background region which is an annulus around the source region. Our background is adjacent to the source region, which makes the background spectrum be in the source direction. We remove six point-like sources from both the continuum map and the data cube to avoid contamination (see Fig. 1). We show the H$_I$ emission, the H$_I$ absorption and the $^{13}$CO emission spectra of G15 (see Figs. 2 and 3). We extract the H$_I$ emission spectra from our source and background regions and then calculate the difference between the two spectra. This difference spectrum is actually proportional to the absorption spectrum, which is used to do absorption analysis. We extract the $^{13}$CO spectrum in our selected background region from the GRS data and compare it with our absorption spectrum.

The H$_I$ absorption feature corresponding to maximum velocity appears at about 140 km s$^{-1}$ (see Figs. 2 and 3). The $^{13}$CO has data between $-5$ km s$^{-1}$ and 135 km s$^{-1}$. There is, in fact, a $^{13}$CO emission feature at 135 km s$^{-1}$ which seems to match the H$_I$ maximum velocity absorption feature. The rms of 0.009 K is obtained by averaging regions with no $^{13}$CO emission-line features in velocity ranges from $-5$ to 10 km s$^{-1}$ and from 60 to 120 km s$^{-1}$. The $^{13}$CO peak temperature at 135 km s$^{-1}$ is 0.047 K, which is a 5σ detection. This supports the H$_I$ absorption feature at about 140 km s$^{-1}$ being real. The velocity of 140 km s$^{-1}$ corresponds to a distance of about 8 kpc based on the Galactic rotation model with $\Theta_\odot = 220$ km s$^{-1}$ and $R_\odot = 8.5$ kpc (Fich et al. 1989). Thus, the lower limit for distance of G15 is 8 kpc.

The H$_I$ emission at a velocity of about 95 km s$^{-1}$ seems to have no associated absorption, which means G15 is likely located in front of this H$_I$ cloud. This velocity corresponds to a far side distance of about 10.5 kpc. The absorption peak at the velocity of about $-20$ km s$^{-1}$ is possibly caused by H$_I$ emission fluctuation, so it is likely not a real feature (see the H$_I$ emission spectra in Figs. 2 and 3). A similar fake absorption feature is often seen in faint SNRs (e.g. Leahy & Tian 2008).

3 RESULTS AND BRIEF DISCUSSION

We obtain a new distance of $9.3 \pm 1.3$ kpc for G15. This is consistent with the $10 \pm 3$ kpc derived from the surface
Fig. 2 The H\textsubscript{I} emission (top panel), and H\textsubscript{I} absorption and \(^{13}\)CO spectra of G15 from SGPS and GRS data (middle panel). The bottom panel shows the relationship between radial velocity and distance.

Fig. 3 The H\textsubscript{I} emission, H\textsubscript{I} absorption and \(^{13}\)CO spectra of G15 from THOR and GRS data. Panel descriptions are the same as those in Fig. 2.

brightness versus diameter relation of Galactic SNRs (Adrián-Martínez et al. 2011). Castelletti et al. (2013) showed an H\textsubscript{I} absorption spectrum and suggested a smaller distance for the remnant. However, we do not find a clue from their paper to reproduce their spectrum, so we believe our careful measurement is more reliable.

The H\textsubscript{I} shell of G15 is 16.5 pc in radius (for 6.1\textquotesingle) at a distance of 9.3 kpc. The PWN inside G15 has a total energy of less than \(1.2 \times 10^{50}\) erg scaled from the value derived in H. E. S. S. Collaboration et al. (2014).

We revise the parameters of G15 using the shell-type model of an SNR in Sturmer et al. (1997). We assume the progenitor supernova of G15 has an explosion energy of \(10^{51}\) erg, a mass of \(8 M_{\odot}\), a magnetic field strength of 1 \(\mu\)G and an interstellar medium (ISM) density of 7 hydrogen atoms per cubic centimeter, so we get the ex-
pansion velocity of about 700 km s$^{-1}$, an age of 11 kyr and a total atomic gas mass that forms the G15 shell of $3.3 \times 10^3 M_\odot$. The estimated parameters may have a 50 percent uncertainty due to the large variance in ISM density.

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