Supernova 1987A:30 years later - Cosmic Rays and Nuclei from Supernovae and their aftermaths
Proceedings IAU Symposium No. 331, 2017
A. Marcowith, M. Renaud, G. Dubner, A. Ray & A. Bykov, eds.

doi:10.1017/S1743921317004914

Measuring distances to Galactic SNRs using the red clump stars

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Abstract. Reliable distances to Galactic Supernova remnants (SNRs) are essential to constrain parameters that reveal the evolutional process of SNRs. We carry out a project to measure SNRs' distances in the first quadrant of the Galaxy. In this project, red clump stars (RCS) are used as standard candle to build the optical extinction (A_V)-(D) distance relation in each direction of extinction-known SNRs. Here, G5.7-0.01, G54.1+0.3 and G78.2+2.1 are taken as typical examples. We obtain the distance of $3^{+0.4}_{-0.3}$ kpc for G5.7-0.01, the lower limit of 5.8 kpc for G54.1+0.3, the upper limit of 2 kpc for G5.7-0.01. The results are consistent with distances from kinematic measurements. Hence, we highlight the RCS method can independently trace the distance to the SNRs.

Keywords. ISM: supernova remnants, methods: data analysis

1. Introduction

Distances of SNRs play important roles in obtaining basic parameters of SNRs like the age, the physical size, the expansion velocity and the explosion energy of the progenitor supernovae. There are several approaches to measure SNRs' distances such as kinematic method, proper motion measurement, Sedov estimate, and Σ-D relation. However, only about 20% of currently known Galactic SNRs have reliable distance measurements (Green 2014).

Red clump stars (RCS) are usually low mass stars in the early stage of core He-burning and concentrate in the color-magnitude diagram (CMD). The helium cores of RCS almost have the same mass. Meanwhile, the absolute magnitudes of RCS weakly depend on metal abundance in infrared band. Therefore, RCS are good enough to be standard candles. Durant & van Kerkwijk (2006) measured the running of reddening with distance in the direction of Galactic anomalous X-ray pulsars and successfully obtained the distances of 5 pulsars. Güver *et al.* (2010) gave a distance estimate to the Low-mass X-ray binaries 4U 1608-52 through the interstellar extinction traced by RCS. Zhu *et al.* (2015) used the similar measurement to determine the distance of SNR G332.5-5.6. We closely follow this method to systematically measure the distances to SNRs in the first Galactic quadrant. Here, we discuss RCS method and the results of SNRs G5.7-0.01, G54.1+0.3 and G78.2+2.1.

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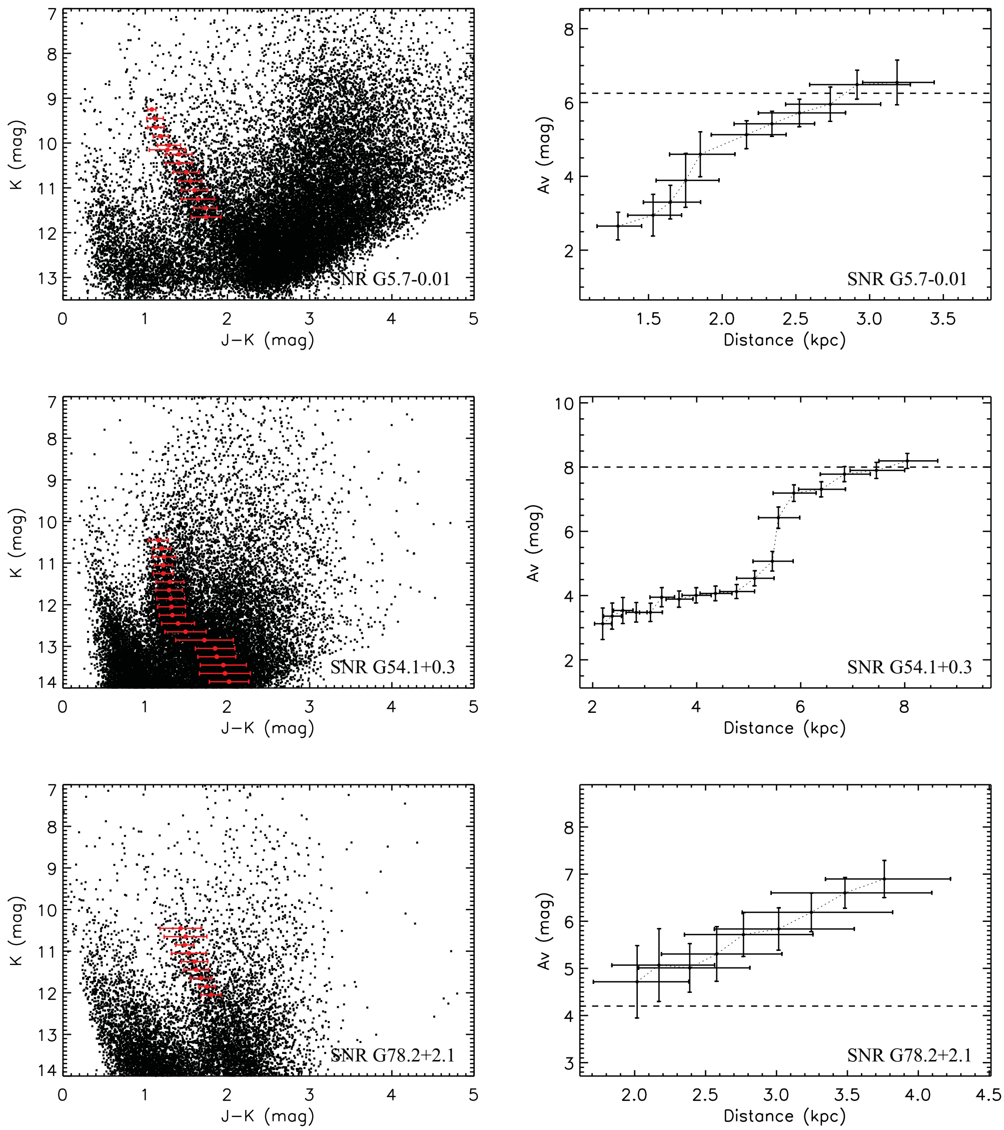

Figure 1. Left column: color-magnitude diagram for stars within 0.5 deg^2 of SNR G5.7-0.01, G54.1+0.3 and G78.2+2.1, respectively. The red dot and lines show the fitted location of the RCS density peak and its extent with 1σ. Right column: The derived A_V-D relation along the direction of G5.7-0.0, G54.1+0.3 and G78.2+2.1. The dashed line is A_v value in the direction of an SNR.

2. Method

Firstly, we select the stars in the 0.5 deg^2 area around the center of a SNR in an interval of (Galactic longitude)$\triangle l\,1°\times\triangle b\,0.5°$(Galactic latitude) from the 2MASS All-sky Point Source Catalog in the J and K_s (hereafter K) band (Skrutskie *et al.* 2006). Then, their magnitudes in J and K bands are used to construct the CMD (K vs. J-K). The RCS concentrate in a distinct region of the CMD (see Fig. 1, left column). The bulk of stars in the left region of the CMD are predominantly main sequence stars; while those in the right region are mainly dwarfs and RGBs. Secondly, we divide the stars in m_K into successive strips. The width of each strip is usually 0.3 mag. It wil be extended

https://doi.org/10.1017/S1743921317004914 Published online by Cambridge University Press

Table 1. Distances measured by RCS method and parameters compiled from literatures.

Sourse Name	N_H ($10^{21} Hcm^{-2}$)	A_V (mag)	Model	D_{known} kpc	Method	Ref.	$D_{(this work)}$ kpc
G5.7-0.01	13±1		Thermal plasma	3.2	kinematic measurement	(1)(2)	$3^{+0.4}_{-0.3}$
G54.1+0.3		8.0±0.7	Spectra fits	6.2	kinematic measurement	(3)(4)	> 5.5
G78.2+2.1		4.2±0.8	H_α/H_β	1.7-2.6	kinematic measurement	(5)(6)	< 2

Reference: (1) Joubert *et al.* (2016); (2) Hewitt & Yusef-Zadeh (2009); (3) Koo *et al.* (2008); (4) Leahy *et al.*(2008); (5) Mavromatakis (2003); (6) Leahy *et al.* (2013)

to 0.5 mag when the RCS are few. To locate the peak density of RCS in one strip, we adopt a Gaussian function to fit the RCS distribution and a power law function to fit the background stars. Then, the best fit produce color index (J-K)$_{peak}$ at the peak density of the RCS distribution. Thirdly, we derive the average extinction for certain range of K by equation 2.1(Güver *et al.* 2010). Finally, distance for RCS of this strip can be derived by equation 2.2. Assuming that the intrinsic color (J-K)$_0$ is 0.67 mag and the mean absolute magnitude of RCS (M_K) band is −1.61 mag.

$$A_V(mag) = \frac{A_K}{0.1137} = \frac{0.67[(J-K)_{peak}-(J-K)_0]}{0.1137} \tag{2.1}$$

$$D(pc) = 10^{[0.2(m_K - M_K + 5 - 0.1137 A_V)]} \tag{2.2}$$

This process is repeated for each stripe until reaching the 2MASS completeness limit. A series of extinction and distance of RCS are produced, then the A_V-D relation is built in the line-of-sight direction of an SNR (see Fig. 1, right column).

3. Results and Discussion

We build the A_V-D relation in the line-of-sight direction of SNRs G5.7-0.01, G54.1+0.3 and G78.2+2.1. In principle, an extinction value indicates one distance in a certain direction since the extinction increases with the growing distance. Overlapping the A_V values of SNRs with the corresponding A_V-D relation, distance are obtained. The parameters we used and the results are listed in Table 1.

For G5.7-0.01, its A_V value is derived from the hydrogen column density (N_H) since the theoretical and observational studies indicate that there is a relation between A_V and N_H. We adopted the average value $A_V/N_H = (2.08 \pm 0.05) \times 10^{21}$ H$cm^{-2}mag^{-1}$ derived from 24 SNRs, 4 planetary nebulae and 65 X-ray binaries in the 1st and 4th Galactic quadrants, which is based on high quality data (Zhu *et al.* in prep.). In this case, the A_V value in the direction of G5.7-0.01 is 6.25±0.48 mag, and the distance to G5.7-0.01 is estimated as 3.0 kpc.

According to the A_V-D relation in the direction of G54.1+0.3, there is an extinction jump around 5.5 kpc. It may be caused by a huge molecular cloud or the increasing population of K dwarf which makes it difficult to identify RCS. In this situation, a conservative estimate should be made as 5.5 kpc for the lower-limit distance.

On the CMD built in the direction of G78.2+2.1, the density of RCS is too small to be identified when the brighter magnitude is below 10 mag. The upper-limit distance of G78.2+2.1 can be estimated as 2 kpc. Leahy *et al.* (2013) determined the distance of G78.2+2.1 from 1.7 kpc to 2.6 kpc. Combining the two results, the distance to G78.2+2.1 is range from 1.7 kpc to 2 kpc.

In summary, our results show that the three distances estimated by RCS method are consistent with those measured by kinematic method. Extinction measurement based on RCS provides a reliable and independent clue to the SNRs' distance. In the future, we will apply this method to systematically measure the distances to Galactic SNRs. With the SNRs' distances, we will further re-calibrate the Σ-D relation and calculate distance-dependent parameters of SNRs.

4. Acknowledgements

We all acknowledge supports from NSFC program (11473038, 11603039).

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