Distances to Two Galactic Supernova Remnants: G32.8-0.1 and G346.6-0.2

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ABSTRACT

There are either a near kinematic distance of 5.5 kpc or a far distance of 8.8 kpc for a Galactic supernova remnant (SNR) G32.8\textdegree-0.1 derived by using the rotation curve of the Galaxy. Here we make sure that the remnant distance is the farther one 8.8 kpc through solving a group of equations for the shell-type remnants separately at the adiabatic-phase and the radiative-phase. For SNR G346.6\textdegree-0.2 we determine its distance also the farther one 11 kpc rather than the nearer one 5.5 kpc.

Subject headings: supernova remnants: general — distance: individual(G32.8-0.1 and G346.6-0.2)

1. Introduction

Distances to SNRs can be estimated by observations of extinction, X-ray, SN magnitude, background object, SNR kinematics and HI absorption, etc. \cite{Strom1988}. In some literatures, the relation between the radio surface brightness (Σ) and the linear diameter (D) is also used to determine the distance when the SNR flux is available \cite{PovedaWoltjer1968,ClarkCaswell1976,Lozinskaya1981, HuangThaddeus1985, DuricSeaquist1986, Guseinovetal2003}. However, for the remnants inside the circle of the Galaxy plane with its radius (R) less than 8.5 kpc yet not too near to the Galactic center, that is the the galactic longitude (l) should be 0° < l < 90° or 270° < l < 360°, then the rotation curve of the Galaxy can be used to derive the SNR distance after measuring and obtaining its LSR velocity (Fig. 1). But usually this method may lead to two distance values of a near one OA and another farther one OB. For two examples here, \cite{Koraleskyetal1998} derived the

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1. Numerical calculations

2.1. At adiabatic phase

Let us list the following group of equations for shell-type remnants at the second stage \cite{WangSeward1984, KoyamaMeguro1987}.
Bignami & Caraveo [1988], Xu et al. [2005],

\[
D_{pc} = 4.3 \times 10^{-11} \left( \frac{E_0}{n_{cm}^{-3}} \right)^{1/5} t_{yr}^{2/5} \tag{1}
\]

\[
\Sigma(D) = 1.505 \times 10^{-19} \frac{S_{1GHz}}{\theta_{arcmin}}
\]

\[
= 2.88 \times 10^{-14} D_{pc}^{-3.8} n_{cm}^{-2} \tag{2}
\]

\[
\left( \frac{E_0}{10^{51} \text{ergs}} \right) = 5.3 \times 10^{-7} n_{cm}^{1.12} v_{Km}^{1.4} s^{-1}
\]

\[
\times \left( \frac{D_{pc}}{2} \right)^{3.12} \tag{3}
\]

Here, \( D_{pc} \) is the SNR diameter in units of pc, \( t_{yr} \) is the remnant age in year, \( n \) is the ISM electron density in \( cm^{-3} \), \( S_{1GHz} \) is the detected fluxes of an SNR in Jy at 1 GHz, \( \theta_{arcmin} \) is the viewing angle in arcmin, \( v = \frac{d\theta}{dt} \) is the velocity of shock waves in km s\(^{-1}\). And we know \( tan(\frac{\theta_{arcmin}}{2}) = \frac{D_{pc}}{d} \), where, \( d_{pc} \) is the distance to a remnant in pc.

We have already known the flux \( S_{1GHz} = 11 \) Jy at 1 GHz, the viewing angle \( \theta = 17 \) arcmin for SNR G32.8–0.1, and flux \( S_{1GHz} = 8 \) Jy, angle \( \theta = 8 \) arcmin for SNR G346.6–0.2 (Green 2009) of which we regard both the remnants evolving at the Sedov-phase. But the linear diameter \( (D) \) (and then distance \( (d) \)), evolving age \( (t) \) and the electron density \( (n) \) are unknown and to be derived. After assuming some SNe initial explosion energy values \( (E_0 = 5 \times 10^{49}, 10^{50}, 5 \times 10^{50}, 10^{51}, 5 \times 10^{51} \text{ergs}) \), then a series of the diameters \( D_{pc} \) (and distance \( d_{pc} \)) of both SNRs are obtained by solving the equations group above (table [1]). Furthermore, when the assumed initial explosion energy \( (E_0) \) changes from \( 10^{49} \text{ergs} \) to \( 10^{53} \text{ergs} \), then the kinematic distance of SNR G32.8–0.1 and G346.6–0.2 also increases (Fig. 2). We can obtain a certain distance value for both remnants corresponding to the typical well-known explosion energy of the SNRs \( E_0 = 10^{51} \text{ergs} \).

**Fig. 1.**— Plot illuminates how a near distance OA and a far distance OB to a calibrator SNR is derived. In this case the remnant distance to the Galactic center should be less than 8.5 kpc, but cannot be too near to the center, i.e. \( 0^\circ < l < 90^\circ \) or \( 270^\circ < l < 360^\circ \). Here \( l \) is the galactic longitude.

Table 1: Derived distances and diameters of SNR G32.8–0.1 and G346.6–0.2 at Sedov-phase after assuming several different initial explosion energies

| \( E_0 \) (ergs) | \( d_{kpc} \) | \( D_{pc} \) | \( d_{kpc} \) | \( D_{pc} \) |
|-----------------|-------------|-----------|-------------|-----------|
| \( 10^{52} \)   | 10          | 50        | 19          | 44        |
| \( 5 \times 10^{51} \) | 9.1         | 45        | 17          | 39        |
| \( 10^{51} \)   | 7.0         | 35        | 13          | 30        |
| \( 5 \times 10^{50} \) | 6.2         | 31        | 11.5        | 27        |
| \( 10^{50} \)   | 4.8         | 24        | 8.8         | 21        |
| \( 5 \times 10^{49} \) | 4.3         | 21        | 7.9         | 18        |

The group of equations are not strictly correct as not to be figured out mathematically, but they are correct enough for us to determine the distance to both SNRs.

From Fig. 2 and table [1] we can see that the most likely kinematic distance to SNR G32.8–0.1 is about 7 kpc relevant typically to \( E_0 = 10^{51} \text{ergs} \).

Since the remnant diameter evolving at the Sedov-phase is typically less than 36 pc (Clark & Caswell 1976, Allakhverdiev et al. 1983, 1985), one can reasonably exclude the two cases of \( E_0 = 10^{52} \text{ergs} \), and \( E_0 = 5 \times 10^{51} \text{ergs} \) for their too large diameters 50 pc and 45 pc. For the smaller initial energy is \( E_0 = 10^{50} \text{ergs} \) and \( E_0 = 5 \times 10^{49} \text{ergs} \), both their outcomes are somewhat unlikely. Moreover, the
Fig. 2.— The initial explosion energy ($E_0$) verses the remnant distance ($d$) at Sedov-phase for both remnants through solving the equations group listed in Sect. 2.1. As the initial energy enhances, the remnants distance also correspondingly increases. Distance value of both SNRs is shown when typically $E_0 = 10^{51}$ ergs.

Fig. 3.— The same as in Fig. 2 but at the snowplough-phase.

typical SNe initial explosion energy is $\sim 10^{51}$ ergs as the black numbers show (table 1). Therefore we subsequently conclude that the distance to SNR G32.8−0.1 is near 7 kpc, that is a little larger or less than 7 kpc. We can see from next subsection that it is larger than 7 kpc. The farther distance 8.8 kpc to the remnant is confirmed as we know later in our work at Sect. 2.2.

Similarly the far distance 11 kpc to SNR G346.6−0.2 is determined which is also consistency with the results done in the next subsection.

2.2. At radiative phase

Analogously we can have the following group of equations for shell-type remnants at the third stage (Kovama & Meguro 1987; Kitayama & Yoshida 2005; Xu et al. 2005)

$$D_{\text{pc}} = 1.42 \left( \frac{E_0/10^{51}\text{ergs}}{n_{cm}^{-3}} \right)^{5/21} t_{yr}^{2/7}$$  \hspace{1cm} (4)

$$\Sigma(D) = 1.505 \times 10^{-19} \frac{S_{1\text{GHz}}}{\theta_{\text{arcmin}}^2}$$

$$= 2.88 \times 10^{-14} D_{\text{pc}}^{-3.8} n_{cm}^{-2}$$  \hspace{1cm} (5)

$$t_{yr} = 10^5 n_{cm}^{-3/4} \left( \frac{E_0}{10^{51}\text{ergs}} \right)^{1/8}$$  \hspace{1cm} (6)

Here, $D_{\text{pc}}$, $t_{yr}$, $n_{cm}^{-3}$, $S_{1\text{GHz}}$ and $\theta_{\text{arcmin}}$ is defined as in Sect. 2.1 as well as their units, and $\tan \left( \frac{\theta_{\text{arcmin}}^{-2}}{2d_{\text{pc}}} \right) = \frac{D_{\text{pc}}}{2d_{\text{pc}}}$. The fluxes $S_{1\text{GHz}}$ and observational angle $\theta_{\text{arcmin}}$ are already known to us for remnants G32.8−0.1 and G346.6−0.2 of which

| $E_0$(ergs) | SNR G32.8−0.1 | SNR G346.6−0.2 |
|------------|----------------|-----------------|
| $10^{54}$  | 13 65          | 24 56           |
| $5 \times 10^{51}$ | 12 59      | 21 51           |
| $10^{51}$  | 9.4           | 17 40           |
| $5 \times 10^{50}$ | 8.5 42     | 16 36           |
| $10^{50}$  | 6.7           | 12 29           |
| $5 \times 10^{49}$ | 6.0 30     | 11 26           |
we suppose here both the remnants evolving at snow-plough phase. When a series of the initial energies \( E_0 = 5 \times 10^{49}, 10^{50}, 5 \times 10^{50}, 10^{51}, 5 \times 10^{51} \) and \( 10^{52} \) ergs are assumed, the remnant diameters \( D_{pc} \) (and distance \( d_{pc} \)) can be derived by solving the equations group above (table 2). The same as in Sect. 2.1 when the assumed initial energy \( E_0 \) enhances from \( 10^{48} \) ergs to \( 10^{53} \) ergs, the SNR G32.8–0.1 and G346.6–0.2 distance values also increase (Fig. 3). Corresponding to the SNRs typical explosion energy \( E_0 = 10^{51} \) ergs one can obtain a certain distance value for both remnants.

One can see the equations (4) and (6) are rather different from equations (1) and (3). But formulae (5) and (2) are completely the same.

From Fig. 3 and table 2 we can see that the most likely distance to SNR G32.8–0.1 is about 9.4 kpc relevant to \( E_0 = 10^{51} \) ergs. Therefore the farther distance 8.8 kpc to the remnant is derived when the distance ranges from 7 kpc to 9.4 kpc by combining the results at both evolving stages of the remnant. One can exclude the two cases of \( E_0 = 10^{52} \) ergs and \( E_0 = 5 \times 10^{51} \) ergs for their too large distance value 13 kpc and 12 kpc. Other two cases of \( E_0 = 5 \times 10^{49} \) ergs and \( 10^{50} \) ergs can also be removed since their linear diameter is less than 36 pc which denotes this remnant is not evolving at the radiative-phase.

As for the remnant G346.6–0.2, in the four cases of \( E_0 = 10^{52} \) ergs, \( 5 \times 10^{51} \) ergs, \( 10^{51} \) ergs and \( 5 \times 10^{50} \) ergs we obtain too large distance values 24 kpc, 21 kpc, 17 kpc and 16 kpc, and could be eliminated. The other two cases \( E_0 = 5 \times 10^{49} \) ergs and \( 10^{50} \) ergs are also impracticable for their small linear diameters 26 pc and 29 pc which means the SNR is not evolving at the radiative-phase. Therefore SNR G346.6–0.2 is most likely evolving at the Sedov-phase with its farther distance 11 kpc which is most near the derived value 13 kpc as its initial energy equals typically to \( 10^{51} \) ergs (Fig. 2).

### Table 3: Illumination about how large the dispersion of the remnant kinematic distance would be induced by the difference of remnant diameters with almost the same surface brightness.

|           | G32.8–0.1 | G346.6–0.2 |
|-----------|-----------|-----------|
| \( D_{pc} \) | \( d_{pc} \) | \( d_{pc} \) |
| 18        | 1.8       | 3.9       |
| 64        | 6.5       | 13.8      |

3. Discussion

#### 3.1. Why do not use the \( \Sigma-D \) relation to determine the distance?

In literatures many authors make use of the relation between the radio surface brightness (\( \Sigma \)) and linear diameter (\( D \)) of supernova remnants to estimate the remnant distance. But here we only adopt a group of equations to confirm the distance to both remnants, because the \( \Sigma-D \) relation will lead to very great deviation on getting a remnant distance.

One can find that the statistical fitting line in the \( \Sigma-D \) plot by (Case & Bhattacharya 1998).

\[
\Sigma(D) = 5.43 \times 10^{-17} D_{pc}^{-2.64} (Wm^{-2}Hz^{-1}sr^{-1})
\]

was widely used to determine the remnant distance when other better methods are not available. As we analyze the data (table 1 in Case & Bhattacharya 1998) and plot (Fig. 1 in Case & Bhattacharya 1998) one can discover that in most case the dispersion of the derived diameter (then the distance) for a certain remnant could be quite large. For example, at the diameter \( D = 18 \) pc, the SNR G327.6+14.6 has the radio surface brightness \( \Sigma = 3.2 \times 10^{-21} Wm^{-2}Hz^{-1}sr^{-1} \), and at \( D = 64 \) pc, the SNR G359.1–0.5 has nearly the same brightness \( \Sigma = 3.7 \times 10^{-21} Wm^{-2}Hz^{-1}sr^{-1} \). The relevant kinematic distance for SNR G32.8–0.1 with the viewing angle \( \theta = 17 \) arcmin would be one 1.8 kpc and another 6.5 kpc (table 3). For SNR G346.6–0.2 with viewing angle \( \theta = 8 \) arcmin the corresponding distance could be one 3.9 kpc and another 13.8 kpc. It is obvious that such great dispersion on the obtained distance is truly impracticable. Furthermore, if the SNR G359.1–0.5 continuously evolves on until the surface brightness reaches the same value \( \Sigma = 3.2 \times 10^{-21} Wm^{-2}Hz^{-1}sr^{-1} \) as that for SNR G327.6+14.6, then the remnant diameter could be larger than 64 pc, which denotes much bigger dispersion for the derived kinematic distance. There are many other different statistical...
results for the fitting line of the remnants $\Sigma - D$ relation [Poveda & Woltjer 1968; Lozinskaya 1981; Huang & Thaddeus 1985; Duric & Seaquist 1986; Guseinov et al. 2003], of which their data dispersion shows much larger. Thus they will lead to bigger deviation when being used to determine the SNRs distance. Therefore we use the group of equations listed in the text to determine the SNR distance can avoid such large dispersion and reach a somewhat good outcome.

3.2. Other remarks

It seems that the SNR G32.8–0.1 may be at the phase-transformation stage just evolving from the Sedov-phase to the snowplough-phase with its linear diameter about 36 pc (table 1) roughly at which the SNRs transform from one phase to another. But the SNR G346.6–0.2 may probably still be in the second-phase. Some days in the future a much better method to estimate this two remnants distance may be available, and the same as a more delicate detect technique which would test or proof our result.

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