GSH 90-28-17: a Possible Old Supernova Remnant

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ABSTRACT
GSH 90-28-17 is a high-latitude galactic HI supershell, identified in the HI supershell catalogs with a velocity of $v_{lsr} \sim -17 \text{ km s}^{-1}$. We used the new Arecibo GALFA-HI survey data which have much higher resolution and sensitivity than what were previously available to re-examine the properties of the supershell. We derived a new distance of 400 pc for GSH 90-28-17 and suggested that it is related to the Lac OB1 association. The radius of GSH 90-28-17 is 66.0±3.5 pc. The HI mass of the shell is $(3.1\pm0.1) \times 10^5 M_{\odot}$. It has an age of $\sim 4.5 \text{ Myr}$ and a total kinetic energy of $(8.2\pm0.3) \times 10^{48} \text{ ergs}$. We extracted radio continuum data for the GSH 90-28-17 region from the 408 MHz all-sky Survey and Bonn 1420 MHz survey, and filtered the diffuse background Galactic emission. A radio loop-like ridge is found to be associated with the HI shell at both frequencies, and shows a nonthermal origin with a TT-plot index of $\alpha=−1.35\pm0.69$. In addition, the pulsar J2307+2225 with a similar distance is found in the shell region. We conclude that GSH 90-28-17 is probably an old, type II supernova remnant in the solar neighborhood.

Key words: ISM: evolution - ISM: supernova remnants - ISM: bubbles - ISM: atoms - ISM: kinematics and dynamics

1 INTRODUCTION
A large number of large-diameter HI shells (or supershells) [Hu 1981, Heiles 1984] have been found in a series of 21 cm line surveys, e.g. Heiles & Habing (1974) and Colomb et al. (1980). It has been suggested that these HI supershells could be the result of some kind of explosion events that occurred in stellar associations, and they are commonly interpreted as old supernova remnants (SNRs) with a typical age of $t \sim 10^5 \text{ yr}$ [Heiles 1984]. As old SNRs evolve into the late stage, the radio surface brightness declines and the interior temperature drops that SNRs gradually fade away. The accumulated neutral hydrogen shells will last longer until the velocity of the expansion decreases down to the random velocity of the interstellar medium (ISM). Those that exploded at very high galactic latitudes are probably able to avoid the interstellar turbulence and supernova explosions that frequently occur in the near-plane region, and can evolve till old age.

GSH 90-28-17 is a high-latitude galactic HI supershell centered at $(l, b) = (90^\circ, -28^\circ)$, with a velocity $v_{lsr} = -17 \text{ km s}^{-1}$. The shell has an angular extent of approximately $18^\circ \times 21^\circ$ in the sky, with an expansion velocity of about $4.5 \text{ km s}^{-1}$. It was first completely identified and listed in the catalog of HI supershells by Heiles 1984 from the data of the Berkely survey [Heiles & Habing 1974] and the HI survey of Colomb et al. (1980). The distance of the shell was estimated as $\sim 3.8 \text{kpc}$ [Heiles 1984] based on a flat rotation curve model for the Galaxy. However, as mentioned in [Hu 1981], distance estimates based on rotational velocity, a method often used in the low latitude region, are not suited for shells at high latitude. [Hu 1981] also identified a partial shell (GS 91−33) of GSH 90-28-17 using a filtering method, and derived a lower limit on the distance of 300 pc for it based on extinction versus distance studies along the line of sight. The kinetic energy of the shell GS 91−33 is estimated to be about $10^{49} \text{ ergs}$ with an age of $1.5\times10^5 \text{ yr}$ [Hu 1981]. Using the distance of 300 pc, the diameter of GSH 90-28-17 is about 100 pc, and it is at a vertical distance of $z \sim 140 \text{ pc}$ from the Galactic plane.

[Sojue & Nakai 1983] searched for low-brightness radio continuum loops possibly associated with HI filaments in the 408 and 820 MHz survey maps. They applied the “background filtering” (BGF) method to remove large-scale background emission, and found a radio continuum loop associated with the HI shell GS 99−26 with a diameter of $7^\circ$, which is in the northeast and adjacent to GSH 90-28-17. The distance of the radio loop is estimated to be $d\sim 570 \text{ pc}$ using the surface brightness-diameter ($\Sigma - D$) relation of Milne (1979), assuming it is a normal SNR [Sojue & Nakai 1983]. However, they excluded the physics association between GS 99−26 and the radio loop by adopting a distance of $3.5 \text{kpc}$ for the HI shell derived from the Galactic rotation curve.

Most supershells are found to be associated with OB associations. In the vicinity of GSH 90-28-17 lies the famous Lac OB1 association located at a distance of 370 pc [de Zeeuw et al. 1999]. Could this supershell have a physical connection with the Lac OB1 association i.e. caused by a progenitor star running out of it? A detailed analysis is required before any firm conclusion can be drawn. As a high latitude supershell far from the plane, the lack of an absorption effect caused by intervening material makes GSH...
2 OBSERVATIONAL DATA

2.1 HI data

The HI data sets come from the recently released Galactic Arecibo L-Band Feed Array HI survey (GALFA-HI), described in detail by Peek et al. (2011). The angular resolution of the survey is about 4'. It covers a wide velocity range from $-700$ km s$^{-1}$ to $+700$ km s$^{-1}$ with a velocity resolution of 0.18 km s$^{-1}$. Typical noise levels are 80 mK in an integrated 1 km s$^{-1}$ channel.

2.2 Radio data

The 408 MHz radio continuum data used here are taken from the 408 MHz all-sky Continuum Survey (Haslam et al. 1982), which is a mosaic of data taken at the Jodrell Bank MkI, Effelsberg 100 m, Parkes 64 m and Jodrell Bank mkIA telescopes. The angular resolution is 0.85. The 1420 MHz radio continuum data are taken from the Bonn 1420 MHz survey (Reich 1982, Reich & Reich (1986) with the Bonn Stockert 25 m telescope. The resolution of the survey is about 35', and the effective sensitivity is about 50 mK T$_B$.

3 RESULTS

3.1 the HI Morphology

In Fig. 1 we show the HI-channel maps of GSH 90-28-17 in the velocity range between $v = -27$ and $-6$ km s$^{-1}$. Each panel represents the integrated image over 19 consecutive channels, yielding a velocity resolution of $\sim 3.4$ km s$^{-1}$. The central velocity of each panel is indicated at the top. The filamentary shell structure is clearly visible with a large void in the center of the images. The center of the shell is at $l = 89^\circ, b = -31^\circ, v = -17$ km s$^{-1}$, which is at a location slightly different from that given in Heiles (1984). The western shell mainly lies at $v \approx -21$ km s$^{-1}$, while the eastern shell lies at $v \approx -12$ km s$^{-1}$. This may indicate that the northern shell is on the far side, or expands backwards, while the southeastern shell is on the near side, or approaching us.

Fig. 2 shows an HI velocity profile through the shell center. Towards the high latitude direction the local background for the HI intensity is not strong. The shell can be clearly identified in the profile as a dip at $v = -17$ km s$^{-1}$. The back cap of the shell is apparent as a bump in the velocity profile at $v \approx -21$ km s$^{-1}$ on the left side of the void, while the front cap at $v \approx -12$ km s$^{-1}$ is a bit confused with the background emission.

In Fig. 3 we present the integrated HI intensity map of GSH 90-28-17, integrating over the velocity range $-28$ to $-15$ km s$^{-1}$. The HI intensity gets enhanced towards the north, which is the direction of the Galactic plane. The three-dimensional morphology of the shell is typically spherical, and extends over approximately 20'. Assuming that the HI emission is optically thin, the HI column density is given by: $N_{\text{HI}} = 1.8 \times 10^{20} \int T(v)dv$ cm$^{-2}$, where $T(v)$ is the brightness temperature at LSR velocity with the background subtracted. We obtain the average column density over the shell region as $(5.3 \pm 0.2) \times 10^{20}$ cm$^{-2}$.

With the sensitivity of GALFA, some patchy HI structures are clearly seen inside the shell. The prominent one is the cloud in the interior of the shell at (Ra, Dec, $v$) = $(22^h45^m, +26^\circ, -13$ km s$^{-1}$), at an average level of $T_B \sim 15$ K. In a largely evacuated area, the existence of such a gas clump is unusual. It is probably a pre-existing molecular cloud that swept by the shocks. Figure 4 shows a profile that is a slice across the shell in the Ra direction. The slice is taken at Dec $+23^\circ37'30.18''$ of the integrated HI map. The mean brightness temperature in the interior of the shell is about $T_B \sim 20$ K, shown as the low-level base structure. The walls show a brightness temperature contrast factor of $2 - 3$ with respect to the shell interior over about 10 resolution grids. The sharpness of the wall indicates the compression is strong, probably associated with a shock.

3.2 The distance

Since many derived properties depend strongly on the adopted distance, an accurate estimate of the distance is essential.

The techniques for distance estimates based on rotation velocity are not suited for shells at high latitude (Hu 1981). We firstly follow the scale height method in Hu (1981) to re-estimate the distance of GSH 90-28-17 using new parameters. The method sets the measured column density of the HI shell, $N_{\text{HI}}$, to be equal to the value one would expect to sweep up with a shell of the measured extent, $\Delta D$, at a distance of $d$, as $N_{\text{HI}} = n(z) d \Delta D$. And it assumes the density distribution of material follows $n(z) = n_0 \exp(-z^2/d^2)$, where $z = d \sin b$ is the height from the Galactic plane. Taking a typical density $n_0 = 1$ cm$^{-3}$, and scale height $h = 130$ pc (Spitzer 1978), the distance $d$ could be solved iteratively in combination with these two equations.

We solve the distance of GSH 90-28-17 with the parameters listed in Table 1. However, the procedure does not produce a consistent solution. Such a situation also happened for many shells in Hu (1981), when the column density attributed to the shell is too large.

| Parameter | Value |
|-----------|-------|
| Center $l$ | $89^\circ$ |
| Center $b$ | $-31^\circ$ |
| Central $v_{\text{lsr}}$ | $-17$ km s$^{-1}$ |
| Distance $d$ | 400 pc |
| Radius $r$ | $66.0 \pm 3.5$ pc |
| Expansion velocity $v_{\text{exp}}$ | $4.5$ km s$^{-1}$ |
| Column density $N$ | $(5.3 \pm 0.2) \times 10^{20}$ cm$^{-2}$ |
| HI gas Mass | $(3.1 \pm 0.1) \times 10^4$ $M_\odot$ |
| Kinetic energy $E_{\text{kin}}$ | $(8.2 \pm 0.3) \times 10^{58}$ ergs |
The physical explanation is that the shells originate in regions of high density, and collect more material than that can be sweep up according to the assumption.

High latitude supershells are usually local gas structures. The absorption associated with the shell of diffuse X-ray emission towards GSH 90-28-17 at 0.25 keV also confirms it as a local shell (in Sect. 3.7). Hu (1981) gave a lower limit for the distance of 300 pc for the partial shell GS 91–33 of GSH 90-28-17 based on extinction versus distance studies along the line of sight. We note that the famous Lac OB1 association (with center around RA=22h35m and Dec=+43.3°) lies in the upper left of GSH 90-28-17 (Chen & Lee 2008). It has an average distance of ~370 pc, which was derived from the Hipparcos data (de Zeeuw et al. 1999). Lac OB1 is part of the local cloud related to the Gould belt, which constitutes the expanding Lindblad ring in whose periphery lies the local stellar associations (Chen & Lee 2008). The enhanced HI column density of GSH 90-28-17 indicates that it probably also lies in the Gould belt, at a distance similar to Lac OB1. The Hipparcos catalog gave an average radial velocity of Lac OB1 of $-13.3 \text{ km s}^{-1}$ (de Zeeuw et al. 1999), which is quite close to that of GSH 90-28-17. Thus we suggest that GSH 90-28-17 is related to the Lac OB1 association. As the distance of nearby association has a noticeable range of a few hundred parsecs, we adopt a distance of 400 pc for GSH 90-28-17 in the latter part of the paper.

3.3 The Physical Properties

The physical properties of GSH 90-28-17, such as expansion velocity and kinetic energy, are re-estimated based on the new distance.

Expansion velocities for shells are usually estimated as half of the total measured velocity width, $\Delta v$, of the shell. The full velocity width of GSH 90-28-17, through the center of the shell, is approximately $\Delta v = 9 \text{ km s}^{-1}$. Thus the expanding velocity is $v_{\text{exp}} \approx 4.5 \text{ km s}^{-1}$. 

Figure 1. HI channel maps of GSH 90-28-17 for the velocity range from $-26.4 \text{ km s}^{-1}$ to $-2.5 \text{ km s}^{-1}$, averaged over 19 consecutive channels, yielding a velocity resolution of $\sim 3.4 \text{ km s}^{-1}$. The central LSR velocities are indicated on top of each panel.
account primordial helium. The kinetic energy associated with the shell is about 0.9 cm
The derived ages of HI shells are usually associated with large uncertainties. Accurate estimation requires a powering source associated with the shell, whose age should be independently measured. However, we can estimate the dynamic age based on models of a shell expanding from the pressure of a hot interior. For GSH 90-28-17, the shock radius follows an expansion law $R \propto t^{0.5}$ (Cioffi et al. 1988), assuming an evolution path similar to that of supernova remnants in the late radioactive phase. Hence the dynamic age $t_0$ in units of Myr is $t_0 = 0.29 R / v_{exp}$, where the radius $R$ is in pc and $v_{exp}$ is in km s$^{-1}$. The resulting dynamic age of GSH 90-28-17 is $\sim 4.5$ Myr. It is relatively old compared with other known Galactic shells (McClure-Griffiths et al. 2002).

In Sect. 3.2, we suggest the shell is associated with the Lac OB1 association. Lac OB1 has an expansion time scale of tens of Myr, on the basis of stellar proper motions and radial velocities (Chen & Lee 2008). It is in its final stage of star formation, and the last star formation episode took place no more than a few Myr ago. The main sequence lifetime of the only O star in Lac OB1 is $3.6$ Myr (Schaerer & de Koter 1997). Based on the age estimation, the star that is the energy source of GSH 90-28-17 is likely to be formed earlier than the last star formation in the association, i.e. has an age of more than a few Myr.

3.4 Radio continuum

We extracted the area of GSH 90-28-17 from the 408 MHz all-sky Survey and Bonn 1420 MHz survey data (Haslam et al. 1982; Reich et al. 1982). The diffuse Galactic background continuum emission decreases with distance from the Galactic plane. A region with weak continuum emission is associated with GSH 90-28-17, with a continuum ridge stretching out over the Galactic plane overlapping with the western shell. In order to reveal radio emission overlapped with the HI shell, we subtracted the smooth Galactic background emission following the same method as Sofue & Nakai (1983). We applied the "background filtering" (BGF) procedure described by Sofue & Reich (1979) to the original radio data. The filtering beam used is about three times the original resolution, 2.5° with cut-values of 50 K $T_B$ at 408 MHz and 2° with 5000 mK $T_B$ at 1420 MHz, respectively. Structures with scale smaller than the filter beam will stand out in the filtered image. Different filtering beam widths (2-
The emission component has a steep index of \( \alpha \) which a spectral break was found in its spectrum and the difference with the expectation of synchrotron emission from old SNRs. The spectral index in an old SNR probably becomes steeper due to a possible nonthermal origin of the radio emission, and it is consistent with the uncertainty of the baselevel.

The TT-plot region is marked in Fig. 5. The resultant TT-plot for the western radio loop-like emission is shown in Fig. 6. It has a steep spectral index of \( \alpha = -1.35 \pm 0.69 \) (\( S \propto \nu^\alpha \)). The error is obtained by fitting the data twice, alternatively taking the data of one of the two wavelengths as the independent variable. The large error of the TT-plot is dominated from the uncertainties of background emission level. However, the steep spectral index indicates a possible nonthermal origin of the radio emission, and it is consistent with the expectation of synchrotron emission from old SNRs. The spectral index in an old SNR probably becomes steeper due to synchrotron losses of electrons. One example is SNR S147, for which a spectral break was found in its spectrum and the diffuse emission component has a steep index of \( \alpha \sim -1.35 \) (Xiao et al. 2008).

Unlike the radio emission from normal SNRs which is usually distributed within the HI shell, the radio loop-like emission is somewhat overlapped with GSH 90-28-17. Detailed confirmation of the nonthermal property of the radio loop-like emission and the association with GSH 90-28-17 requires new high-resolution radio observations towards this direction. Assuming there is a physical association with GSH 90-28-17 requires new high-resolution radio observations towards this direction.

Figure 5. The filtered 408 MHz and 1420 MHz continuum image obtained by applying the “background filtering” (BGF) method. The contours show the integrated HI map smoothed to 1', which start at 22.5 K km s\(^{-1}\) and increase in steps of 15 K km s\(^{-1}\). The box marks the TT-plot region.

Figure 6. The TT-plot of the radio loop-like emission associated with the western shell of GSH 90-28-17. Both residual maps after BGF filtering at 408 MHz and 1420 MHz are smoothed to a common resolution of 1', and the grids are re-sampled to one point within one beam. The fitted spectral index is \( \alpha = -1.35 \pm 0.69 \).

3') essentially show the same features, except that a smaller beam width will slightly reduce the intensity. The filtered maps obtained by applying the BGF method are present in Fig. 5. A prominent radio loop-like ridge with a length of approximately 10' is clearly revealed to be associated with the western HI shell at both frequencies. A radio point-like source with peak temperatures of 680 mK at 1420 MHz seems coincident with an HI enhancement. The excess brightness of the loop-like ridge over the background is 3–6 K at 408 MHz, and 60–100 mK at 1420 MHz. The rms fluctuations \( \Delta T_b \) in the residual images of 408 MHz and 1420 MHz in Fig. 5 are 0.4 K and 10.0 mK, respectively.

Although the BGF technique is effective for demonstrating faint features, the brightness temperatures on the resulting map usually give underestimated values. In order to investigate the spectral index properties of the radio loop-like emission, we applied the TT-plot, which is unaffected by the uncertainty of the baselevels, at these two frequencies. Both residual maps after BGF filtering at 408 MHz and 1420 MHz are smoothed to a common resolution of 1' before calculating the spectral index. And the grids are re-sampled to one point within one beam to avoid the oversampling. The TT-plot region is marked in Fig. 5. The resultant TT-plot for the western radio loop-like emission is shown in Fig. 6. It has a steep spectral index of \( \alpha = -1.35 \pm 0.69 \) (\( S \propto \nu^\alpha \)). The error is obtained by fitting the data twice, alternatively taking the data of one of the two wavelengths as the independent variable. The large error of the TT-plot is dominated from the uncertainties of background emission level. However, the steep spectral index indicates a possible nonthermal origin of the radio emission, and it is consistent with the expectation of synchrotron emission from old SNRs. The spectral index in an old SNR probably becomes steeper due to synchrotron losses of electrons. One example is SNR S147, for which a spectral break was found in its spectrum and the diffuse emission component has a steep index of \( \alpha \sim -1.35 \) (Xiao et al. 2008).

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3.5 Polarization

We extracted the 21 cm polarized intensity map of the GSH 90-28-17 region (Fig. 7) from the polarization survey made with the DRAO 26 m telescope (Wolleben et al. 2006). This map includes the large-scale polarized emission component at an absolute zero level with an angular resolution of 36'. We found no prominent polarization emission associated with the radio loop-like ridge, except for some polarization patches in the shell region with randomly dis-
distributed polarization angles. This evidence does not seem to support the SNR origin of the shell. However, the magnetic field in the radio ridge might be weakened as the SNR evolves into the late stage. And it is also possible that the radio ridge depolarized the emission from larger distances.

3.6 Pulsars

We searched through the ATNF pulsar catalog to find possible associated pulsars. Three pulsars (J2234+2114, J2229+2643 and J2307+2225) are located within the HI shell. J2229+2643 has a short period of $P \sim 0.003$ s, and seems to be a millisecond pulsar which was formed by accretion. It could be excluded from the candidates for possible association with the HI shell. The periods of J2234+2114 and J2307+2225 are 1.4 and 0.5 s, with distances of 3.38 and 0.38 kpc, respectively, from the Dispersion Measure based on the Galactic electron density model [Taylor & Cordes 1993]. Although the characteristic age of the pulsar J2307+2225 is about 9.8 $\times$ 10^6 yr [Camilo & Nice 1995], derived from the ratio $p/2p$ ($p$ is the period of the pulsar), the true age of the visible pulsar should be younger than that from this linear derivation, and rarely exceeds some 10^6 yr [Smith 1977]. It appears that J2307+2225 is the most probable candidate pulsar, and its position is marked in Fig. 7. If J2307+2225 is associated with GSH90-28-17, we can estimate the kick velocity of the pulsar from its current location relative to the center of the shell, which is about 14 km s$^{-1}$.

3.7 Comparison with Other Wavelengths

We check the diffuse X-ray emission towards GSH90-28-17, using the publicly available data from the ROSAT all-sky background survey [Snowden et al. 1997]. The 0.25, 0.75 and 1.5 keV emission is compared with the HI distribution. There is clear evidence of 0.25 keV absorption associated with the shell region. The RASS Band 2 (0.14–0.284 keV) image of GSH90-28-17 overlaid with contours of HI integrated intensity is shown in Fig. 8. At 0.25 keV, one optical depth corresponds to HI column densities of about $1 \times 10^{20}$ cm$^{-2}$ [Snowden et al. 1997], which is lower than the averaged column density in the HI shell region. Considering an averaged space density of 0.1 cm$^{-3}$ (averaged over the local bubble) along the line of sight, the mean free path for 0.25 keV X-rays is about $\sim 324$ pc. Thus most of the R2 band emission must have originated locally. This further excludes the possibility of a farther distance for GSH90-28-17. The absorption becomes less prominent at 0.75 keV, and is not seen at 1.5 keV. The mean free paths for X-rays in the higher energy bands are much longer. At the 1.5 keV band, one optical depth is $\sim 5 \times 10^{21}$ H cm$^{-2}$ [Snowden et al. 1997].

4 DISCUSSION

Both the energy released in a stellar wind and a supernova explosion could create an HI shell structure with size similar to that of GSH90-28-17. Although the pulsar J2307+2225 detected within the HI shell and the association with non-thermal radio continuum emission at 408 and 1420 MHz seem to favor a supernova event. The expansion kinetic energy of GSH90-28-17 is comparable with another HI shell G132.6-0.7-25.3 [Normandeau et al. 2000]. The size of GSH 90-28-17 is about twice that of G132.6-0.7-25.3 (radius 33 pc), which is probably caused by the relatively low ambient density. Normandeau et al. (2000) found that the B1 Ia star BD +60°447 could have been the energy source of the shell by means of its stellar wind, but they also could not exclude the possibility of an old supernova remnant.

In this section, we shall explore the possibility of stellar wind and supernova formation scenarios of GSH90-28-17 based on their theoretical models, individually. If the observed HI shell is the result of only one stellar wind, what would be the source star of GSH90-28-17? As a less massive progenitor star would be required in the supernova case, then which type of supernova it would be?

4.1 Stellar wind scenario

The stellar wind of a single O-type or an early B-type star would be strong enough to blow a bubble while on the main sequence, and then no longer be capable of maintaining the ionization of the shell. The energy injected by the stellar winds $E_\nu = Mv_\nu^2/2$ is related to the luminosity of the star. Thus we can estimate the luminosity of the star required to blow the kinetic energy of GSH 90-28-17.
The relation between mass-loss rate $\dot{M}$ and the stellar luminosity is obtained from Table 1 of Lamers et al. (1999) for a sample of O and B stars. The wind velocity $v_w$ is also related to the stellar luminosity at an average level of about 2000 km s$^{-1}$. The main-sequence lifetime of stars with different luminosity could be estimated through the stellar evolution models for a solar metallicity of Bressan et al. (1993).

When the interstellar bubble expands, only a fraction of the stellar wind energy $\epsilon \dot{E}_w$ is transferred to the kinetic energy of the HI gas. Some fraction is converted into thermal energy when the stellar wind shock sweeps up the interstellar medium. The expected energy conversion efficiency $\epsilon$ is on the order of 0.2 or less (McCray et al. 1983), and sometimes can be as low as 0.02 (Cappa et al. 2003) when severe energetic losses occur.

If we adopt a typical conversion efficiency of 0.2, the expansion energy of GSH 90-28-17 requires a star with luminosity $\log(L/L_\odot)=5.3$ at solar metallicity. This luminosity implies there is a main-sequence star with mass of 30 M$_\odot$, lifetime of 6.2 Myr (Bressan et al. 1993), and spectral type of approximately O7V. The age of GSH 90-28-17 estimated from the expansion law is $\sim$4.5 Myr, similar to the main-sequence lifetime of a 30 M$_\odot$ star.

The distance of GSH 90-28-17 is local. If the star still exists, it should be detectable. Based on the star evolutionary tracks (Bressan et al. 1993), and using the aforementioned luminosity and effective temperature, the star should now appear as a B1 star. However, there are very few massive stars in the center of the shell. As we searched the SIMBAD database, there are only 12 B stars, of which the earliest is a B8-type star, which is located near/in the shell walls. The central star is a B8 star, with a distance of $\sim$870 pc, which is too far to be associated with the HI shell. Thus the stellar wind (blown-bubble) scenario seems to be difficult for explaining the origin of the shell.

### 4.2 A supernova explosion

The association between non-thermal radio continuum emission at 408 and 1420 MHz with GSH 90-28-17, and the pulsar J2307+2225 detected within the HI shell indicates that G90-28-17 is probably an old supernova remnant.

After the cooling-dominated radiative expansion phase, old SNRs will evolve into a late stage, and eventually merge with the interstellar medium and become indistinguishable. Adopting a distance of 400 pc, we extrapolate the initial explosion energy of GSH 90-28-17 from the maximum observable radius and the ambient environment following the evolution model for a late stage SNR (Cioffi et al. 1988; Thornton et al. 1998).

$$R_{\text{merge}} = 51.3 E_0^{31/98} n_0^{-18/49} Z^{-5/98}$$

where $R_{\text{merge}}$ is the maximum observable radius of the shell in units of pc, $E_0$ is the explosion energy in units of $10^{51}$ ergs, $n_0$ is the mean ambient particle density of 0.9 cm$^{-3}$, and Z is the metallicity normalized to the solar value. Adopting a metallicity $Z = 1$, the energy required to generate a shell by a single SN explosion is estimated to be about $2.3 \times 10^{51}$ ergs, which is the typical explosion energy output of a type II supernova.

The size and age of GSH 90-28-17 is comparable to supernova remnants that are considered to be very old in the Galaxy. Good examples of such type are the Monoceros SNR (G205.5+2225) detected within the HI shell indicates that G90-28-17 is almost dissolved with no observational traces of the S1 supernova remnant are very similar to those of GSH 90-28-17.

The SNR interpretation of GSH 90-28-17 makes it among the examples of such type are the Monoceros SNR (G205.5+2225) measured by Heiles (1984), corresponding to these two supernova remnants that are expanding with different velocities. The properties of the S1 supernova remnant are very similar to those of GSH 90-28-17. This shell is almost dissolved with no observational traces (except for the polarization emission loop), and could not be found in total intensity surveys.

The SNR interpretation of GSH 90-28-17 makes it among the
J2307 at 1420 MHz. The TT-plot index of the radio loop-like ridge is 28-17 at both frequencies. The excess brightness of the radio ridge is a radio loop-like ridge associated with the western shell of GSH 90-28-17. Ground emission from 408 and 1420 MHz survey maps, and found the energy source would be a 30 M$\odot$ for the GSH 90-28-17. If it has an origin from stellar wind, the Chinese Academy of Sciences, and thank Dr. James Wicker for proofreading the manuscript.

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oldest SNRs known. Our case study of this source also demonstrates the capability of high-resolution HI surveys in finding the oldest supernova remnants. Though the radio and X-ray emission in the center of the remnant is rather weak, we are still able to see the well-defined HI shell of GSH 90-28-17. It is generally assumed that the accumulated expanding gas shell will survive 10 times longer until the expansion velocity decreases down to the random velocity of the interstellar medium (McKee & Ostriker 1977), and then dissolves into the ambient medium. As the shell remains as a high-density enhancement in a low-density region for a long time, it provides a good environment to allow star formation to progress after a single trigger event. Stil & Irwin (2001) have interpreted another HI supershell GSH 138-01-94 as an old SNR with a similar age of 4.3 Myr in the far outer Galaxy. It was later suggested by Kobayashi et al. (2008) to have triggered the star formation in Digel’s cloud 2. As a high latitude supershell far from the Galactic plane, GSH 90-28-17 greatly avoids the absorption effect caused by intervening material, and provides a good example to study the last phase of evolution for old SNRs in a relatively peaceful environment of the Lac OB1 association.

5 CONCLUSIONS

The properties of the HI supershell GSH 90-28-17 are re-examined using the new Arecibo GALFA-HI survey data with greatly improved resolution and sensitivity. We suggest that GSH 90-28-17 is related to the Lac OB1 association, with a distance of 400 pc. The radius of GSH 90-28-17 is 66.0±3.5 pc. The HI mass of the shell is about $(3.1±0.1) \times 10^4$ M$_\odot$. It has an age of ~ 4.5 Myr and a total kinetic energy of about $(8.2±0.3) \times 10^{48}$ ergs.

We used the filtering algorithm (BGF) following Sofue & Nakai (1983) to subtract the large-scale diffuse Galactic background emission from 408 and 1420 MHz survey maps, and found a radio loop-like ridge associated with the western shell of GSH 90-28-17 at both frequencies. The excess brightness of the radio ridge over the background is $3-6$ K at 408 MHz and $60-100$ mK at 1420 MHz. The TT-plot index of the radio loop-like ridge is $\alpha = -1.35 \pm 0.69$, shows a nonthermal origin. In addition, the pulsar J2307+2225 is found inside the shell region at a similar distance.

We discussed the possibility of stellar wind and SNR scenarios for the GSH 90-28-17. If it has an origin from stellar wind, the energy source would be a 30 M$_\odot$, O7 star, and should now be observable as a B1 star. However no star earlier than B8 is found within the shell. We conclude that GSH 90-28-17 is probably an old, type II SNR in the Galaxy around the solar neighborhood.

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