Atlas of CO-line Shells and Cavities around Galactic Supernova Remnants with FUGIN*

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Abstract

A morphological search for molecular shells and cavities was performed around 63 Galactic supernova remnants (SNRs) at $10^\circ \leq l \leq 50^\circ$, $|b| \leq 1^\circ$ using the FOREST Unbiased Galactic Imaging survey with the Nobeyama 45 m telescope CO-line data at high-angular ($20''$) and high-velocity (1.3 km s$^{-1}$) resolutions. The results are presented as supplementary data for general purpose investigations of the interaction between SNRs and interstellar matter in the form of an atlas of CO-line maps superposed on radio continuum maps at 20 cm along with a list of their kinematic distances determined from CO-line radial velocities.

* Unified Astronomy Thesaurus concepts: Supernova remnants (1667); Molecular clouds (1072); CO line emission (262); Interstellar medium (847); Catalogs (205)

Supporting material: figure set

1. Introduction

The interaction between shock waves of supernova remnants (SNRs) and molecular clouds has been a long-standing issue in the physics of the interstellar medium (ISM) (Chevalier 1977, 1999; Shull 1980; Lucas et al. 2020). The major concerns about the interaction are the generation of interstellar turbulence (Kilpatrick et al. 2016), triggering or suppression of star formation (McKee & Ostriker 1977; Cox et al. 1999; Seta et al. 2004), and cosmic ray acceleration (Fujita et al. 2009; Kuriki et al. 2018; Maxted et al. 2019; Sano et al. 2019).

Extensive observations of the association of molecular clouds with well-studied SNRs have been obtained in recent decades by molecular-line observations (Tatematsu et al. 1990; Koo & Moon 1997b; Tian et al. 2007; Ranasinghe & Leahy 2018; Lee et al. 2020). The current “association” has been discussed mainly in terms of the coincidence of the distance of an SNR measured by some means with the kinematic distance of the cloud from radial velocity, leaving a large uncertainty on the order of ~1 kpc. On the other hand, association based on the morphological shell structure concentric to the SNR’s shock front has been obtained in few cases.

In this paper, we perform a systematic search for CO-line shells and/or cavities based on morphological association with the SNRs listed in Green’s catalog (http://www.mrao.cam.ac.uk/surveys/snr; Green & Dewdney 1992; Green 2009, 2019). We use $^{12}$CO and $^{13}$CO ($J=1-0$) line channel maps from the FOREST Unbiased Galactic Imaging survey with the Nobeyama 45 m telescope (FUGIN) data set (Minamidani et al. 2016; Umemoto et al. 2017).

The purpose of this paper is to present the results in the form of an atlas of the identified molecular cavities and shells, and to provide a finding chart for general purpose research into the interaction between SNRs and the ISM in the Galactic disk.

Table B1 lists the SNRs from Green’s catalog located in the FUGIN survey area at $10^\circ \leq l \leq 50^\circ$, $|b| \leq 1^\circ$, and $198^\circ \leq l \leq 236^\circ$. Figure 4 shows the positions of the SNRs on the color-coded maps of the peak $T_B$ of the $^{12}$CO, $^{13}$CO, and $^{18}$O line emission in the first Galactic quadrant (Umemoto et al. 2017). In order to compare the distributions of the CO-line emission with radio distribution of the SNRs, we extracted 21 cm radio continuum maps of the SNRs from the archival websites of the Multi-Array Galactic Plane Imaging Survey (MAGPIS; Helfand et al. 2006), VLA Galactic Plane Survey (VGPS; Stil et al. 2006), and the Effelsberg radio continuum survey (Reich et al. 1997). We summarize the parameters of the data sets in Table 1.

The FUGIN project provided high-sensitivity, high-spatial, and high-velocity resolution, wide-velocity (482 channels $\times 0.65$ km s$^{-1}$) and wide-field ($40'' \times 2''$ along the Galactic plane from $l = 10^\circ$ to $50^\circ$) coverage by ($l, b, v_{lsr}, T_B$) cubes in the $^{12}$CO, $^{13}$CO, and $^{18}$O ($J=1-0$) lines. The full beamwidth at half maximum of the telescope was $15''$ at the $^{12}$CO ($J=1-0$) line frequency, and the velocity resolution was 1.3 km s$^{-1}$. The effective beam size of the final data cube was $20''$, and the rms noise levels were ~1 K. The final 3D FITS cube had a voxel size of $(\Delta l, \Delta b, \Delta v_{lsr}) = (8''5, 8''5, 0.65$ km s$^{-1}$), and is available as archival data.

3. Atlas

3.1. Identification

We present the atlas of molecular cavities, shells, and partial arcs apparently surrounding the SNRs by superposition of $^{12}$CO channel maps on radio continuum maps at 20 cm.

The search for a CO shell associated with an SNR was done by the following procedure. Since the distance of an SNR is unknown, or uncertain even if it exists, its radial velocity is not known, so the search for the shell structure was done in all the 462 channels of the CO data cube from $-100$ to $200$ km s$^{-1}$ one channel after the other for each SNR.
First we display the radio continuum image on the screen, and superpose a channel map (\(T_B\) map) on the same screen. Then, the CO channel is changed from the first to the 462nd step by step. Numerous CO clouds and filaments will pass by, mostly foreground and background emissions, but at a certain velocity channel, a possible shell/cavity/arc appears apparently associated with the SNR’s shell edge.

Once such a candidate was found, its nearby channels are inspected more carefully, the clearest shell feature was chosen accordingly associated with the SNR’s shell edge.

Table B1 lists the Galactic positions (\(l, b\)), radial velocities (\(v_{\text{lat}}\)), kinematic distances (\(d\)), and linear diameters (\(D\)) of the candidates’ cavities and/or shells of the analyzed SNRs. References to molecular-line observations, which report the association of the same or close radial velocities, are cited in the last column. Objects without references are mostly new measurements currently with no information about molecular gas association.

The measured results are presented in the form of \(T_B\) maps (sometimes \(I_{\text{CO}}\) maps) in the \(^{12}\text{CO}\)-line emission of the CO shells, arcs, and/or concentric alignment of clumps, as superposed on 20 cm radio continuum maps, in the online figure set associated with Figure 5 in Appendix C. We also present superposed \(^{13}\text{CO}\) and \(^{12}\text{CO}\) maps by R (red) and G (green) color-coded images in order to show the degree of condensation of the molecular gas density.

The association of the SNR and the identified molecular shell/cavity has been obtained purely by morphological inspection into the CO-line channel maps. This means that, despite the coincidence of the concave edge of a CO cloud with the SNR’s outer edge, the physical (true) association cannot be proved from the present analysis, which applies to all the SNRs studied in this paper. A direct way to prove the association is their distance coincidence on the line of sight with a sufficiently high accuracy, e.g., within an error of a few tens of parsecs. However, the kinematical distance from the molecular line includes an uncertainty of \(\sim 1\) kpc, distance estimation by a SNR’s brightness to diameter (\(S\sim D\)) relation yields an even larger uncertainty, and the method to measure the radio continuum absorption by an HI cloud includes the problem of the association of the HI and CO clouds themselves.

Thus, the atlas presents only the candidate molecular structures. More advanced discussion about the interaction may be obtained by further, sophisticated observations of a signature of the physical compression by a shock wave such as shock-induced molecular lines (Ziurys et al. 1989; Koo & Moon 1997b; Seta et al. 2004; Sashida et al. 2013).

Nevertheless, it may be worthwhile to comment that the radial velocities determined here, hence kinematical distances, of the identified molecular shells for some typical SNRs are in good agreement with those currently reported in the literature such as G11.17-0.35 at \(v_{\text{lat}} = 33\) km s\(^{-1}\) (Kilpatrick et al. 2016), and W44 at 40–50 km s\(^{-1}\) (Seta et al. 2004), for example. In Table B1 we cite more references, in which the same or close velocity clouds are identified by independent CO-line observations.

### 3.2. Morphological Classification

An SNR interacting with a molecular cloud will deform the cloud to make a concave boundary with respect to the SNR’s center. Thereby, the resulting cloud morphology will depend on the extent and density of the cloud. We categorize the structure of a shell or a cavity of the CO brightness distribution apparently surrounding a SNR as follows.

(i) **Cavity (Ca)**: When the cloud is extended to be comparable to or larger than the SNR’s size, a round cavity is created around the SNR due to the dissociation of molecular gas and its accumulation at the shock front. If the cloud size is sufficiently large, the cavity will be fully embedded in the cloud, making a round shape in the sky. We define such a case as a cavity with a completeness of 1% or 100%, and introduce a completeness parameter or the shell measure, \(\kappa = 1\). If the cloud size is comparable or smaller, the dissociation and/or compression will take place partially, forming an open cavity to the intercloud space. Such a partial cavity may be categorized by its completeness or shell measure with \(\kappa < 1\), depending on the fraction of the boundary from a perfect loop.

(ii) **Shell (Sh)**: If the cloud’s density is lower, the gas will be accumulated or piled up around the shock front, making a shell structure. The shell may be categorized by its completeness from \(\kappa = 1\) showing a perfect loop, or partial loops with \(\kappa < 1\).
3.3. Distances

The radial velocity, $v_r = v_{lsr}$, at a distance $d$ orbiting around the Galactic Center is related to the circular rotation velocity $V(R)$ as a function of the Galactocentric distance $R$ as

$$v_r = \left( \frac{R_0}{R} - V_0 \right) \sin \theta, \quad (1)$$

where $R$ is the Galactocentric distance related to $d$ and Galactic longitude $l$ by

$$d = R_0 \cos l \pm \sqrt{R^2 - R_0^2 \sin^2 l} \quad (2)$$

We assume here $V_0 = 238 \, \text{km s}^{-1}$ and $R_0 = 8.0 \, \text{km s}^{-1}$ (Honma et al. 2015), and adopt the most recent rotation curve derived by the compilation of determined circular velocities in the last two decades as shown in Figure 3 (Sofue 2020). Here, we approximate the rotation curve by an analytic expression,

$$V(R) = \left( \frac{V_1}{1 + (R/a)^3} + \frac{V_2}{1 + (R/b)^2} \right) (R/c) \quad (3)$$

The parameters, $V_1 = 67$, $V_2 = 1000 \, \text{km s}^{-1}$, $a = 3.5 \, \text{kpc}$, $b = 0.44 \, \text{kpc}$, and $c = 1 \, \text{kpc}$, were determined by the iterative fitting of the function to the data by trial and error, until one gets a satisfactory reproduction of the data within the radius range, 1.4 to $\sim 10 \, \text{kpc}$, necessary for the present analysis. The adopted curve is shown by the thick line in Figure 3.

For a given set of $v_r$ and $l$, we can determine $R$ by iteration using Equations (1) and (3), and the distance $d$ is obtained by Equation (2). In Table B1 we list the determined distances and diameters of the SNR. The errors are calculated using the uncertainty of radial velocity of the CO line in the measured value as well as the interstellar turbulence, $\delta v_{lsr} \sim 5 \, \text{km s}^{-1}$, and the uncertainty in the rotation velocity, $\delta V_{rot} \sim 5 \, \text{km s}^{-1}$, propagating through the above equations to $d$. The uncertainties in $R_0$ and $V_0$ are not included.

3.4. Molecular Mass

The molecular mass of associated clouds is one of the most essential quantities. However, the present resolution, $20'' \sim 0.5 \, \text{pc}$ at $5 \, \text{kpc}$ for example, is a few orders of magnitude wider than the expected thickness of shock-compressed filaments at the SNR fronts (Lucas et al. 2020). So, we are not able to estimate meaningful mass of the directly associated molecular gas to the SNRs.

Instead, we try here to estimate the upper limit to the associated cloud for G11.17-0.35 as a typical example. By measuring the excess $T_b$ at the edge of the SNR over that in the ambient emission outside the SNR, the upper limit mass may be calculated by

$$M \sim \mu m_H 2\pi \kappa R_5 \delta R_{\text{beam}} X_{\text{CO}} \int \delta T dv, \quad (4)$$

where $\mu \sim 2.6$ is the reduced mass per $\text{H}_2$ molecule for solar abundance, $m_H$ is the hydrogen mass, $X_{\text{CO}} \sim 2 \times 10^{20} \, \text{cm}^{-2}$ [K km s$^{-1}$]$^{-1}$ (Sofue & Kohno 2020) is the conversion factor, $R_5$ is the SNR radius, $\delta R_{\text{beam}} = R_{\text{beam}}$ is the beamwidth at the object, $\kappa$ is the cavity/shell measure, and $\delta T$ is the excess brightness temperature of the $^{12}\text{CO}$ line at the intensity peak along the shell or the edge of cavity contacting the SNR.
Figure 2. Example of molecular cavity/shell of Ca/Sh 50 toward SNR G11.17-0.35 at $v_{\text{lsr}} = +32.925 \text{ km s}^{-1}$ by (top left) $^{12}$CO contours from 7 K every 1 K on 20 cm in red; (top right) $^{13}$CO contours from 7 K every 0.5 K, superposed on a gray-scale map of 20 cm radio continuum from 0 to 0.03 Jy beam$^{-1}$; (middle left) $^{12}$CO contours from 2 K every 1 K; (middle right) three-color composite images of $^{13}$CO (red: auto), $^{12}$CO (green: auto), and 20 cm (blue: auto; magenta contour interval by 5 mJy beam$^{-1}$); (bottom left) $^{12}$CO-line spectrum at the western edge; (bottom right) $^{12}$CO $T_B$ across the SNR’s center along $b = -0^\circ.34$ (dashed) and $-0^\circ.36$ (full line), showing the “cavity” property. All figures of the studied SNRs are presented in Appendix C and the online figure set.
For G11.17-0.35 at 33 km s$^{-1}$ (Figure 2), we obtain $\delta T \sim 5$ K and $\kappa \sim 0.5$, and the possibly associated molecular mass is shown to be $M < \sim 10^2$ and $< \sim 10^3 M_\odot$ for the near and far distances, respectively. Similar estimation applies to most of the observed partial CO shells in the analyzed SNR, but we do not present the results for individual objects, because the estimations are simply upper limits to the physically meaningful masses, which are supposed to be a few orders of magnitude smaller, as discussed above.

4. Summary

We obtained a systematic search by morphology for cavity and/or shell structures of $^{12}$CO- and $^{13}$CO-line emissions adjacent to 63 cataloged Galactic SNRs. Such a search was possible only by careful inspection of individual channel maps of brightness temperature with high-velocity and high-angular resolution from the FUGIN CO survey. The result is presented in the form of a table of kinematical distances of the CO shells, and an atlas of CO-line $T_B$ maps as superposed on the radio continuum maps of the SNRs, which will be useful for general purpose investigations of the interaction between SNRs and the ISM in the Galaxy.

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Facilities: Nobeyama 45 m, VLA, Effelsberg 100 m.

Software: astropy (Astropy Collaboration et al. 2013).

Appendix A

SNR Distribution

Figure 4 shows the positions of the SNRs from Green’s catalog on the CO-line brightness map (red: $^{12}$CO, green: $^{13}$CO, blue: C$^{18}$O).

Figure 3. The most recent rotation curve (thin line with circles and standard errors; Sofue 2020), and the model rotation curve used that is expressed by Equation (3).
Figure 4. Green’s SNRs (cyan crosses) superposed on the FUGIN CO map (https://nro-fugin.github.io) of the peak brightness temperatures of $^{12}$CO, $^{13}$CO, and C$^{18}$O lines in red, green, and blue, respectively (Umemoto et al. 2017). The Galactic longitude ranges are of (a) $10^\circ \leq l \leq 20^\circ$, (b) $20^\circ \leq l \leq 30^\circ$, (c) $30^\circ \leq l \leq 40^\circ$, and (d) $40^\circ \leq l \leq 50^\circ$, respectively.
Appendix B
Table of SNRs

Table B1 lists the analyzed objects and derived parameters for the candidate CO-line features adjacent to the SNRs.

| (a) | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | (j) | (k) | (l) | (m) |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( \ell, b \) | \( v_{lsr} \) | Size | SNR | \( f'_{\text{marm}} \) | Type | \( \delta_{\text{mm}} \) | \( \delta_{\text{km}} \) | \( \delta_{\text{marm}} \) | \( D_{\text{mm}} \) | \( D_{\text{km}} \) | Name | References |
| ----- | ----- | ------ | ----- | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 11.00-0.05 | +40 | 11.9 | S | 1.3 | Sh 50 | 6 | 11.6 | 0.3 | 12.0 | 33.4 | 15 |
| 11.1-0.7 | +33 | 11.7 | 1.0 | Ps 50 | 3.5 | 12.2 | 0.3 | 8.9 | 31.2 | 12 |
| ... | ... | ... | S | 2.3 | N | 10 |
| 11.17-0.35 | +33 | 4.4 | C | 22 | Ca 50 | 3.7 | 12.0 | 0.3 | 4.3 | 14.0 | 15 |
| 11.2+0.12 | +56 | 12.10 | S | 2.3 | Ps 30 | 6 | 10.8 | 0.2 | 11.6 | 25.7 | 15 |
| 11.4-0.1 | +30 | 8.8 | S? | 6 | Ca 60 | 3.4 | 12.3 | 0.3 | 8.0 | 28.5 | 15 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 11.89-0.23 | +49.8 | 4.4 | F | 0.7 | Ca 50 | 4.5 | 11.1 | 0.2 | 5.3 | 13.0 | 15 |
| 12.0-0.1 | +37.4 | 77 | ? | 3.5 | Ps 50 | 3.8 | 11.8 | 0.3 | 7.7 | 24.1 | 15 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 13.45-0.14 | +24 | 5.4 | S | 3.5? | Ca 50 | 2.7 | 12.9 | 0.2 | 3.5 | 16.8 | 15 |
| (14.1-0.1) | ... | ... | S | 0.5 | N | 15 |
| (14.3+0.1) | ... | ... | S | 0.6 | N | 15 |
| 15.42+0.16 | +34 | 15.14 | S | 5.6 | Sh 60 | 3.2 | 12.3 | 0.3 | 13.3 | 51.7 | 15 |
| 15.9+0.2 | +29 | 7.5 | S? | 5.0 | Ps 50 | 2.8 | 12.6 | 0.3 | 4.8 | 21.7 | 15 |
| (16.0-0.5) | ... | ... | S | 2.7 | N | 15 |
| (16.4-0.5) | ... | ... | S | 4.6 | N | 15 |
| 16.75+0.08 | +47 | 4.4 | C | 3.0 | Ca 90 | 3.8 | 11.6 | 0.3 | 4.4 | 13.5 | 15 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 17.05-0.05 | +31.0 | 6.6 | S | 0.4 | Ca 50 | 2.8 | 12.5 | 0.3 | 4.1 | 18.2 | 15 |
| ... | ... | ... | S | 1.4 | Ca 30 | 5.6 | 9.7 | 0.2 | 8.2 | 14.1 | 15 |
| 18.1-0.1 | +49 | 8.8 | S | 4.6 | Ps 50 | 3.7 | 11.5 | 0.3 | 8.7 | 26.7 | 15 |
| 18.6-0.2 | +66 | 6.6 | S | 1.4 | Ca 50 | 4.5 | 10.7 | 0.2 | 7.8 | 18.7 | 15 |
| 18.8+0.35 | +20 | 17.11 | S | 33 | Ps 60 | 1.9 | 13.3 | 0.4 | 7.4 | 52.8 | 15 |
| (19.1-0.2) | ... | ... | S | 10 | N | 15 |
| 20.0-0.2 | +65 | 10.10 | F | 10 | Ca 60 | 4.3 | 10.7 | 0.2 | 12.6 | 31.2 | 15 |
| (20.4+0.1) | ... | ... | S? | 9? | N | 15 |
| (21.0-0.4) | ... | ... | S | 1.1 | N | 15 |
| (21.5-0.9) | ... | ... | C | 7 | No 20 cm | 15 |
| (21.6-0.8) | ... | ... | S | 1.4 | No 20 cm | 15 |
| 21.8-0.6 | +83 | 20.20 | S | 65 | Sh 70 | 5.0 | 9.9 | 0.2 | 28.9 | 57.6 | 15 |
| 22.7+0.2 | +75 | 26.26 | S? | 33 | Ps 60 | 4.6 | 10.2 | 0.2 | 34.7 | 76.9 | 15 |
| 23.3+0.3 | +70 | 27.27 | S | 70 | Ps 70 | 4.3 | 10.4 | 0.2 | 34.1 | 81.3 | 15 |
| (23.6+0.3) | ... | ... | S | 8? | N | 15 |
| 24.7+0.6 | +60 | 15.15 | S? | 8 | Ca 30 | 3.8 | 10.7 | 0.3 | 16.7 | 46.7 | 15 |
| 24.7+0.6 | +112 | 30.15 | C? | 20? | C/P 60 | 6.3 | 8.2 | 0.4 | 39.1 | 50.6 | 15 |
| 27.4+0.0 | +101 | 4.4 | S | 6 | Ca 60 | 5.8 | 8.4 | 0.4 | 6.8 | 9.8 | 15 |
| (27.8+0.6) | ... | ... | S | 30 | F | 15 |
| 28.62-0.10 | +86 | 13.9 | S | 3? | Ca 60 | 5.0 | 9.0 | 0.3 | 15.7 | 28.5 | 15 |
| 29.6+0.1 | +99.2 | 5 | S | 1.5? | Sh 50 | 5.9 | 8.0 | 0.5 | 8.6 | 11.7 | 15 |
| 29.70-0.26 | +52 | 3 | S | 10 | Ca 50 | 3.3 | 10.6 | 0.3 | 2.9 | 9.3 | 15 |
| ... | ... | ... | S | 30 | F | 15 |
| 31.5-0.6 | +87.5 | 18.18? | S? | 2? | Ps 50 | 5.2 | 8.4 | 0.3 | 27 | 44 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 31.9+0.0 | +107 | 7.5 | S | 25 | Ca 50 | 6.8 | 8.8 | ... | 12 | 2391 | 15 |
| 32.1-0.9 | +95 | 40.40? | S? | N | 5.9 | 7.7 | 0.5 | 69 | 89 | 15 |
| 32.4+0.1 | +10.8 | 6.6 | S | 0.25? | Ca 100 | 0.79 | 12.7 | 0.2 | 1.4 | 22 | 15 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 32.8-0.1 | +74 | 17.17 | S? | 11? | Ps 10 | 4.4 | 9.0 | 0.25 | 22 | 45 | 15 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 33.2-0.6 | +54 | 18.18 | S | 3.5 | Ps 20 | 3.3 | 10.1 | 0.2 | 17 | 53 | 15 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 33.9 | +91 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

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Table B1
(Continued)

| (a) | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | (j) | (k) | (l) | (m) |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( \ell, b \) | \( v_\text{lsr} \) | Size | SNR | \( f_{1\,\text{GHz}} \) | Type | \( \delta_{\text{near}} \) | \( \delta_{\text{far}} \) | \( D_{\text{near}} \) | \( D_{\text{far}} \) | Name | References |
| \( ^\circ, ^\circ \) | (km s\(^{-1}\)) | (\( \prime \times \prime \)) | | (Jy) | (\( \times 10^3 \)) | (kpc) | (kpc) | (pc) | (pc) | | |
| 33.7+0.05 | +85 | 10 10 S | 20 | Ca 70 | 5.2 | 8.1 | 0.4 | 15 | 24 | Kes 79 | 20 |
| 34.7-0.4 | +40 | 35 27 C | 250 | Ca 60 | 2.6 | 11 | 0.2 | 23 | 95 | W44 | 2 |
| \cdots | +52 | | | Ca 75 | 3.2 | 9.9 | 0.2 | 29 | 89 | W44 | 12 |
| 35.6-0.4 | +55 | 15 11 S? | 9 | Pa 20 | 6.5 | 6.5 | \cdots | 24 | 24 |
| \cdots | +90 | | | Ca 20 | 3.5 | 9.3 | 0.3 | 26 | 68 |
| 36.6-0.7 | +57 | 25 25? S? | 1.0 | Ca 20 | 5.1 | 7.8 | 0.4 | 37 | 57 |
| \cdots | +79 | | | Ca 20 | 3.2 | 9.2 | 0.3 | 6.5 | 18.5 | 3C396 | 21 |
| 39.2-0.3 | +51 | 8 6 C | 18 | Ca 30 | 4.2 | 8.2 | 0.5 | 8.4 | 16.6 | | 8 |
| \cdots | +65 | | | Ca 60 | 3.8 | 8.4 | 0.3 | 24 | 54 |
| 40.5-0.5 | +58 | 22 22 S | 11 | Ca 70 | 2.1 | 10.0 | 0.3 | 2.0 | 9.7 | 3C397 | 6 |
| 41.1-0.3 | +32 | 4.5 2.5 S | 25 | Ca 60 | 2.5 | 9.6 | 0.3 | 2.4 | 9.4 |
| \cdots | +38 | | | Ca 100 | 3.8 | 8.2 | 0.4 | 11 | 24 |
| 41.5-0.4 | +58 | 10 10 S? | 1? | Ca 50 | 4.6 | 7.3 | 0.5 | 11 | 17 |
| 42.0-0.1 | +66 | 8 \times 8 S? | 0.5? | Ca 60 | 4.6 | 7.3 | 0.5 | 11 | 17 |
| (42.8+0.6) | +24 | 24 24 S | 3? | N | \cdots | \cdots | \cdots | \cdots | \cdots | \cdots | \cdots |
| 43.3-0.2 | +10 | 4 3 S | 38 | Ca 50 | 0.7 | 11 | 0.3 | 0.7 | 11 | W49B | 21 |
| \cdots | +45 | | | Ca 60 | 3.0 | 8.7 | 0.3 | 3.0 | 8.7 | W49B | 13, 21 |
| \cdots | +62 | | | Ca 100 | 4.4 | 7.3 | 0.7 | 4.4 | 7.3 | W49B | 21 |
| 45.7-0.4 | +26 | 22 22 S | 4.2? | Pa 40 | 1.8 | 9.4 | 0.3 | 11 | 60 |
| \cdots | +48.5 | | | Pa 20 | 3.4 | 7.8 | 0.4 | 22 | 50 |
| 46.8-0.3 | +52 | 15 S | 17 | Ca 70 | 3.9 | 7.1 | 0.5 | 17 | 31 | HC30 |
| 49.2-0.7 | +50 | 30 30 S? | 160? | Pa 30 | 4.1 | 6.4 | 0.7 | 35 | 56 | W51C | 1 |
| \cdots | +60 | | | Ca 50 | 5.2 | 5.2 | \cdots | 46 | 46 | W51C |
| 205.5+0.5 | +10 | 220 S | 140 | N | 0.98 | \cdots | 0.3 | 63 | \cdots | Monoceros | 17 |
| \cdots | +20 | | | N | 2.2 | \cdots | 0.3 | 139 | \cdots | Monoceros |
| 213.0-0.6 | +9 | 160 \times 140? S | 21 | 0.4 N | 0.7 | \cdots | 0.3 | 32 | \cdots | 17 |
| \cdots | +21 | | | N | 1.8 | \cdots | 0.3 | 80 | \cdots |

Notes. Columns: (a) Galactic position; (b) CO-line radial velocity from the present measurements using FUGIN; (c) apparent major-axis and minor-axis sizes, \( \theta_x \) and \( \theta_y \); (d) SNR type; (e) radio flux at 1 GHz; (f) CO cavity or shell measure; (g) near solution of the distance for the CO radial velocity; (h) far distance; (i) distance error; (j) linear diameter for near distance \( D = \sqrt{\theta_x \theta_y \delta} \); (k) for far distance; (l) name. (m) References to other CO-line observations: (1) Koo & Moon (1997a); (2) Seta et al. (2004); (3) Yang et al. (2006); (4) Zhou et al. (2009); (5) Su et al. (2009); (6) Jiang et al. (2010); (7) Paron & Giacani (2010); (8) Su et al. (2011); (9) Paron et al. (2012); (10) Paron et al. (2013); (11) Petriella et al. (2013); (12) Yoshiike et al. (2013); (13) Zhu et al. (2014); (14) Su et al. (2015); (15) Kilpatrick et al. (2016); (16) Voisin et al. (2016); (17) Su et al. (2017); (18) Ranasinghe & Leahy (2017); (19) Ranasinghe & Leahy (2018); (20) Kuriki et al. (2018); (21) Lee et al. (2020). * “N” stands for no possible cavity/shell in CO being recognized. Columns (a), (c), (d), and (e) are from Green’s catalog (Green 2009).
Appendix C

Figure Set

Figure 5 and the online figure set show the analyzed results of individual SNRs.

Figure 5. Molecular cavity/shell of Ca/Sh 50 toward SNR G11.00-0.05+40.725, 40.075 km s$^{-1}$. (Left) $^{12}$CO contours superposed on the radio continuum map in red. Contours start at 2 K by step 1 K. (Right) Two-color composite image of CO $T_B$, red and green showing $^{12}$CO and $^{13}$CO, respectively, superposed on the 20 cm radio map.

(The complete figure set (47 images) is available.)

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