A λ20cm Survey of the Galactic Center Region I: Detection of Numerous Linear Filaments

F. Yusef-Zadeh
Department of Physics and Astronomy, Northwestern University, Evanston, Il. 60208
(zadeh@northwestern.edu)

J. Hewitt
Department of Physics and Astronomy, Northwestern University, Evanston, Il. 60208
(j-hewitt@northwestern.edu)

W. Cotton
National Radio Astronomy Observatory, Charlottesville, VA 22903 (bcotton@nrao.edu)

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This is a first in a series of papers presenting a sensitive $\lambda 20\text{cm}$ VLA continuum survey of the Galactic center region using new and archival data based on multi-configuration observations taken with relatively uniform $uv$ coverage. The high dynamic range images cover the regions within $-2^\circ < l < 5^\circ$ and $-40' < b < 40'$ with a spatial resolution of $\approx 30''$ and $10''$. The wide field imaging technique is used to construct a low-resolution mosaic of 40 overlapping pointings. The mosaic image includes the Effelsburg observations filling the low spatial frequency $uv$ data. We also present high resolution images of twenty three overlapping fields using DnC and CnB array configurations. These high-resolution images are sensitive to both compact and extended continuum features with a wide range of angular scales with rms noise of 0.2 mJy beam$^{-1}$ in the outer parts of the Galactic center region. The survey has resulted in a catalog of 345 discrete sources as well as 140 images revealing structural details of HII regions, SNRs, pulsar wind nebulae and more than 80 linear filaments distributed toward the complex region of the Galactic center.

These observations show the evidence for an order of magnitude increase in the number of faint linear filaments with typical lengths of few arcminutes. Many of the filaments show morphological characteristics similar to the Galactic center nonthermal radio filaments (NRFs). The linear filaments are not isolated but are generally clustered in star forming regions where prominent NRFs had been detected previously. The extensions of many of these linear filaments appear to terminate at either a compact source or a resolved shell-like thermal source. A relationship between the filaments, the compact and extended thermal sources as well as a lack of preferred orientation for many RFs should constrain models that are proposed to explain the origin of nonthermal radio filaments in the Galactic center.

*Subject headings:* ISM: Clouds—ISM: general—supernova remnants—HII regions: ISM—surveys
1. Introduction

There is considerable interest in the physical processes occurring in the Galactic center region where a number of unique thermal and nonthermal radio continuum sources are hosted including the bright nonthermal compact radio source Sgr A*. This compact source coincides with a concentration of dark matter considered to be a massive black hole at the dynamical center of the Galaxy (e.g. Eckart & Genzel 1996; Ghez et al. 1998). This interest has lead to a number of studies of star formation activity in this region as well as to a study of the origin of unusual nonthermal activities. Radio continuum structures have been studied with single-dish and interferometric measurements on scale-sizes ranging between a few degrees to sub-arcsecond resolutions over the last two decades (Sofue and Handa 1984; Reich, Sofue & Fürst 1987; Handa et al. 1987; Seiradakis et al. 1989; Haynes et al. 1992; Gray 1994a,b; LaRosa et al. 2000).

A number of recent large-scale interferometric studies of the Galactic center have been carried out with the Molongolo Observatory Synthesis Telescope (MOST), the Very Large Array (VLA) of the National Radio Astronomy Observatory\(^1\) as well as the Giant Meterwave Radio Telescope (GMRT). MOST observations at 843 MHz surveyed the region between \(l = \pm 5^\circ\) and \(b = \pm 2^\circ\) and detected a number of supernova remnant (SNR) candidates as well as “the Snake”, a nonthermal radio filament (NRF) near the Galactic center. Their analysis showed in excess of 14 SNR candidates toward the Galactic center (Gray et al. 1991; Gray 1994a,b), some of which have been confirmed at 610 MHz by GMRT observations (Roy and Rao 2002; Bhatnagar 2002). In another study, large scale imaging of the inner four degrees of the Galactic center region was carried out using one VLA pointing at 327 MHz (Anantharamaiah et al. 1991; Pedlar et al. 1989; LaRosa et al. 2000; Nord et al. 2003) as well as at 74 MHz (Brogan et al. 2003). Nord et al. (2003) used wide field imaging technique and detected additional linear filaments and determined radio spectra of a number of radio sources at low frequencies. More recently, polarization study of

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the linear filaments found originally at 327 MHz showed that three of these features are linearly polarized at 5GHz (LaRosa et al. 2004). VLA observations at 1.4 GHz have also been made with a number of antenna pointings but proper mosaicing of these fields have not been carried out previously (e.g. Liszt 1985, 1992; Liszt and Spiker 1995).

Motivated by the ability to use wide field imaging technique to correct non-coplanar effects, as was done at 327 MHz (LaRosa et al. 2000), we present radio images of the Galactic center region at 1.4 GHz based on archival and new observations taken in the last twenty years. We believe the data presented here can be combined with other multi-wavelength observations to enhance our understanding of this complex region of the Galaxy. A more detailed analysis of the data will be described elsewhere; here, we concentrate on the morphology and distribution of filamentary structures in the surveyed region. A wide variety of linear filaments with knotty but continuous appearance are reported. We argue that most of the new filaments are likely to be emitting synchrotron radiation, are of the same class of NRFs and are associated with star forming regions. In particular, we present evidence of thermal extended sources and/or compact sources located at the extensions of the terminus of these filaments. Such a relationship should constrain models that are proposed to explain the origin of nonthermal radio filaments in the Galactic center.

The structure of the paper is as follows: we first describe observations and data reductions followed by presenting a 20cm mosaic image with a resolution of 30″. Because of a rich collection of radio sources in this region, the mosaic image is divided into eight segments, each of which is displayed as contours and grayscale images. In section 4, we discuss high-resolution (≈ 10″) images of Sgr C (G359.5-0.0) and its extensions, Sgr E (G358.7-0.0), the radio Arc (G0.2-0.0) and its extensions, Sgr A (G0.0-0.0), Sgr B1 (G0.5-0.0), Sgr B2 (G0.07-0.0) and radio continuum sources distributed between Sgr B2 and l≈ 5°. A catalog of point sources using the high resolution data has also been created. Earlier catalog of small diameter sources over a much larger region of the inner Galaxy has been presented based on snapshot observations with the VLA at 20cm by Zoonematkermani et al. (1990). Since the emission at 20cm is dominated by extended features in the Galactic plane of the Galactic center region, our survey data sample the uv plane reasonably
well and therefore is more complete and more sensitive to identify the point sources distributed within the inner two degrees of the Galactic center region than earlier studies.

2. Observations and Data Reductions

2.1. Low-resolution data

We have used 40 overlapping $\lambda 20\text{cm}$ fields based on archival and new VLA observations in its compact, hybrid array configuration. Nine of the pointings were carried out on January 30, 2003 using the compact DnC array configuration of the VLA. Figure 1a shows a schematic diagram of all the pointings represented by black and gray circles of diameter $30'$ corresponding to the 20cm primary beam. The individual pointings have different $uv$ coverage but the combined data sample the $uv$ plane reasonably well. In fact, none of the selected archival data were based on snapshot observations shorter than 30 minutes. Field 34 has been observed using the DnC array but in the HI spectral line mode with excellent $uv$ coverage; the continuum channel was selected for this survey data. Each individual data set was edited, calibrated and self-calibrated before the final images were constructed.

Prior to the construction of the final low-resolution mosaic image, the individual images were convolved to $30''$ and were incorporated with single-dish observations based on Effelsburg data (Reich 1982; Reich and Reich 1986) in order to account for the lack of low spatial frequency $uv$ data. Single dish images and those derived from different VLA configurations were combined using the "feathering" technique. The feathering technique consists of making a weighted average of the images to be combined in the spatial frequency (Fourier transform) plane. The weighting is designed to produce a combined image which incorporates the spatial frequencies from the most relevant image at each location in the spatial frequency plane and with a smooth transition between images. The relevant range of spatial frequencies for a given image is determined by the configuration of the array used to make an interferometric image or the size of the single dish and can be parameterized by the beam size. The images being combined should collectively and
adequately sample all spatial frequencies out to that corresponding to the full resolution of the combined image. After combination in the Fourier domain, the image is then transformed back to the image domain. In the implementation used here, the weights in the Fourier domain have a constant value except for a Gaussian profile hole in the center where the Gaussian is the Fourier transform of the (Gaussian) beam of the next lowest resolution image. Since the images being combined are restored CLEAN or single dish images, they have already been tapered at spatial frequencies not sampled by the instrument making the image. Thus, the limited resolution of an instrument should not be reflected in the spatial frequency weighting function used for its image. The combined image is normalized by repeating the process replacing the input images by images of a unit point source convolved to the same resolution. This technique very effectively selects the portions of the $uv$-plane best sampled in each of the input images. A proper mosaic image of the overlapping $\lambda 20$ cm fields was constructed using FLATN in AIPS.

Table 1 gives a listing of the antenna pointings in celestial and galactic coordinates and the rms noise of each individual image which has been combined with the Effelsburg data. The rms noise of the low-resolution images corresponding to the fields outside the central degree of the Galactic center is $\approx 0.5$ mJy beam$^{-1}$ when the single-dish data has not been added; the rms noise increases by a factor of 20 in the central 0.5 degrees toward the Sgr A region.

### 2.2. High-resolution data

Additionally, we have constructed a mosaic image with the highest resolution available for a given pointing. Most of the individual sources have resolutions about $10''$. The high resolution data are carried out in the hybrid DnC and CnB array configurations but there are also few pointed observations in the D, C, B and A arrays. The single-dish data has not been added to these images with the exception of the region between $l \approx 1^\circ$ and $5^\circ$ where the VLA and Bonn images are feathered together, as seen in Figure 26. Table 2 gives a listing of 23 antenna pointings in celestial and galactic coordinates and the array configurations that were employed. Column 1 in both Tables 1a,b corresponds to the field number in the decreasing order of Galactic longitude.
Figure 1b displays a schematic diagram of all the high-resolution pointings, similar to that shown in Figure 1a. Multi-configuration data are combined in the $uv$ plane, self-calibrated before the final images are constructed. Sgr A, Sgr B and the Radio Arc (G0.2-0.0) have high-resolution A-array data and “feathering” technique was used in combining the data in the image plane. In order to bring out small-scale faint features, some of the final images were constructed by restricting the low-spatial frequency data to $uv > 0.4k\lambda$. This cut-off of the inner $uv$ plane suppresses the strong background emission arising from the Galactic center region.

The criterion that we selected to identify the linear filaments was by detecting them either in more than one 20m field of view or in images taken in two different array configurations of the VLA. In addition, the length-to-width ratio of the filaments had to be greater than few in order to avoid shell-like structures such as HII regions with sharp edges. All the observed fields overlapped with each other and were observed in more than one array configuration. In addition, because of the spatial coherence of the long filaments, we were able to identify them easily even though the surface brightness of some of the faint filaments was similar to the background rms level. The probability of positive detection of these faint filaments increases as their lengths extend over many pixel sizes.

Table 3 lists all the filaments described in this paper. Column 1 shows the sources within which the filaments are found or associated with, in the order in which they are described here. Columns 2 and 3 show the nomenclature used on figures and the corresponding Galactic coordinates. Column 4 shows whether the filaments are identified as NRFs or considered as candidate NRFs. Using high resolution images, the length, the orientation and the integrated flux density of background-subtracted filaments are given in columns 5, 6 and 7, respectively. The flux densities of the filaments that are very faint and/or suffer from a negative bowl caused by the lack of low-spatial frequency $uv$ data have not been estimated. Column 8 show the references to the previously identified radio filaments.

The compact point sources detected in high-resolution data are fitted with a two-dimensional single Gaussian using SAD in AIPS. Columns 1 to 8 of Table 4 lists the galactic and celestial
coordinates, the peak and integrated flux, the size and the corresponding errors, respectively, for each compact source found in the high resolution data. Column 9 shows the field numbers (as shown in Figure 1b) corresponding to the high resolution data where compact sources are fitted with signal-to-noise greater than 5. Column 10 indicates a flag given by SAD when there is a high point in the residual image of the fit, thus the fit is poor. The sources that are unresolved in this table are blanked in columns 6–8. A total of 345 compact sources were identified as listed in the point source catalog, all of which have sizes less than 1′. A catalog of extended compact sources beyond 1′ scale length as well as the analysis of the point source catalog will be given elsewhere.

3. Low-resolution λ20cm Mosaic Image

Figure 2a shows a mosaic image of the central region between $-5^\circ < l < 2^\circ$ and $-40^\prime < b < 40^\prime$ along the Galactic plane. The high dynamic range image with a resolution of 30″ shows the bright saturated central region (in black color) where Sgr A, B, C and the Arc are located; the inclusion of single-dish data has accounted for the low spatial frequency visibility data. The images that do not include the low spatial frequency $uv$ data produce artifacts around bright and extended continuum sources. Figure 2b shows a close-up view of the central Sgr A region. The low-resolution mosaic image is displayed in eight different grayscale and contour panels in Figures 3 to 10. With the addition of low-spatial frequency $uv$ data, the background continuum emission varies between 20 and 40 mJy beam$^{-1}$ across the surveyed region.

4. High-resolution λ20cm Continuum Images

In the following sections, the large-scale distribution of high-resolution images are first displayed before close-up views of individual sources are shown in grayscales and contours. A brief description of the new filamentary structures is described. Unlike the low-resolution data, the single-dish data have not been folded into the high-resolution VLA data. We first concentrate on the bright sources on the negative galactic longitudes before we show the images of the Arc, Sgr A
and Sgr B. Finally, we present a high resolution mosaic image of radio features distributed at high positive longitudes beyond Sgr B2 (G0.7-0.0).

4.1. Sgr C (G359.5-0.0) & its Northern and Southern Extensions

4.1.1. Large-scale View

Sgr C lies at the western "footprint" of a large-scale radio structure (aka “The Galactic center lobe” or G359.4-0.5) that has been detected using single-dish observations of the Galactic center (e.g., Sofue and Handa 1984). Figure 9a shows a low-resolution image of Sgr C and its northern extension known as the western Galactic center lobe. This diffuse and extended structure runs away from the galactic longitudes ranging between $l \approx -0.5^\circ$ and $-0.2^\circ$ toward positive galactic latitudes. The large-scale diffuse western Galactic center lobe appears to coincide with AFGL 5376 (Uchida, Morris and Serabyn 1990).

Sgr C hosts one of the most prominent radio continuum sources in the Galactic center region with its nonthermal and thermal radio continuum components (Liszt 1992; Liszt and Spiker 1995). Multiple filaments of Sgr C appear to end abruptly inside a molecular cloud HII complex with a velocity of $-65 \text{ km s}^{-1}$ (Liszt 1992; Liszt and Spiker 1995). Figure 11a shows the high-resolution image of Sgr C and a large number of labeled linear features in its vicinity. Figure 11b, which is based only on B-array observations, shows a large, southern view of the Sgr C region. The fields to the northwest and southwest of Sgr C are shown in Figures 11c and 11d where prominent NRFs known as G359.54+0.18 (the ripple filament) and G359.1-0.2 (the Snake filament) are displayed. The southern extension of the Snake is shown in Figure 11e. This figure shows the field containing the southern end of the Snake, SNR G359.1-0.5, SNR G359.0-0.9 (LaRosa et al. 2000; Bamba et al. 2000) and G359.23-0.82 (the Mouse) within which a young pulsar has recently been found (Yusef-Zadeh and Bally 1987; Camilo et al. 2002). Highlights of some of the features found in these fields are described below.
4.1.2. Individual Images

A large number of new NRF candidates are detected throughout Sgr C and its northern and southern extensions. Table 3 lists a total of 33 filaments associated with the Sgr C region. All these filaments are distributed within the large-scale western Galactic center lobe which appears to have a counterpart at 8\(\mu\)m and 20\(\mu\)m (Bland-Hawthorn & Cohen 2003; Uchida, Morris and Serabyn 1990). The relationship between the filaments of Sgr C and the Galactic center lobe, AFGL 5356 is not well understood. However, the presence of these linear features may suggest that thermal and nonthermal features in this region may have the same origin. A number of the new filaments are faint with surface brightness 1–5 mJy beam\(^{-1}\) and do not appear to be preferentially oriented perpendicular to the Galactic plane. The names of the filaments, as indicated in Table 3 with their Galactic coordinates, are labeled on Figures 11 and 12.

**G359.45-0.06 (RF-C1)** The most prominent nonthermal radio filaments (RF-C1 in Table 3) run along the eastern edge of the Sgr C thermal source. Figures 12a,b show close-up views of the Sgr C HII region and the NRFs (RF-C1 in Fig. 11a) as they cross the HII region. We note that the vertical nonthermal filaments of Sgr C become brighter and narrower as they curve toward the diffuse semi-circular HII region at its base near G359.57–0.067. Also a point source at a level of \(\approx 5\) mJy beam\(^{-1}\) is located at one end of a subfilament in RF-C1 near G359.43+0.03. Similar behavior has been detected in the NRFs of the radio Arc as the NRFs cross the HII regions associated with the Arched filaments (Yusef-Zadeh and Morris 1988). These images show morphological evidence for the likely association of the nonthermal radio filaments of Sgr C and its HII region. The contours of Sgr C filament in Figure 12b also indicates that while the filaments are enveloped by weak continuous emission, the core of the filamentary structure appears bright and knotty as the filaments extent toward the Sgr C HII region (G359.43-0.09).

**G359.54+0.18 (RF-C3)** Another well-known nonthermal system of filaments is G359.54+0.18 (aka "the ripple filament") which lies to the north of Sgr C. The ripple filament resolves into
multiple parallel components with a terminus that flares in the direction toward the Galactic plane (Bally and Yusef-Zadeh 1989; Yusef-Zadeh, Wardle and Parastaran 1997). Figures 11c and 12n show grayscale images of this nonthermal source which extends for about 15′ (36 pc at the distance of 8.5 kpc). This sharp drop-off in the brightness distribution of the filament in the direction away from the Galactic plane is reminiscent of the network of filaments in the Arc as they become diffuse and faint in the direction normal to the Galactic plane. Earlier observations had detected the brightest component of G359.54+0.18 which extends for about 5′. The newly detected diffuse emission extending to the northwest of G359.54+0.18 has a typical surface brightness of $\sim 1$ mJy beam$^{-1}$ which is weaker than the the brightest segment of RF-C3 by a factor of 20. Evidence for such a large-scale nonthermal filament indicates that the western Galactic center lobe has a nonthermal component.

G359.49-0.12 (RF-C4): Another system of filaments (RF-C4 in Figures 11a and 12d) appears to act as a bridge between two diffuse features at G359.47-0.17 and G359.57-0.07. This system breaks up into at least three components aligned along its long axis. A faint diffuse emission at a level of 0.2 mJy beam$^{-1}$, though not displayed in Figure 12d, appears to connect the southwestern component to G359.47-0.17. If these components are part of a coherent filamentary structure, the brightness of the filament must vary by a factor of 5 to 10 along its 6′ extent, as seen in Figure 12d. We believe the knotty structure of G359.49-0.12 consists of two filaments running parallel to each other but with non-uniform surface brightness along their lengths. The lack of faint diffuse emission between the northeastern and southwestern filaments may be due to the missing low spatial frequency uv data which has not been added to high resolution images. Although no diffuse emission has been detected between the individual filaments, we believe the alignment of these linear features suggests that they have the same origin. Similar alignment of NRFs has been detected in the Arc as the filaments cross G0.18-0.04 (Yusef-Zadeh and Morris 1987b).

G359.44+0.01 (RF-C5) Figure 12c shows a close-up view of the northern extension of Sgr C where a curved filamentary structure (RF-C5) appears to cross the Sgr C filaments (RF-C1).
**G359.34-0.15 (RF-C13)** Figures 11a and 12e show two different views of RF-C13 which consists of multiple parallel filaments brightening at G359.32-0.16 where they are curved most. A diffuse feature G359.27-0.22 is noted in Figure 12e at the southwestern extension of this system of filamentary structure. We also note another filamentary feature G359.32-0.18 (RF-C29), as seen Figure 12e, with an extent of $\approx 2'$ and a position angle of $34^0$ to the south of RF-C13 at G359.32-0.18.

**G359.21+0.54 (RF-C16)** This new filament, as shown in Figure 11c, extends for about 10' and is one of the narrowest (width of $\approx 10''$) and most uniform filaments found in the Galactic center region in terms of its surface brightness ($\approx 1$ mJy beam$^{-1}$). The southern extension of this filament, when extrapolated, appears to cross a point source at G359.26+0.42 (see Table 4). The filament is aligned along the direction of the western component of the Galactic center lobe.

**G359.44+0.44+0.14 (RF-C6) and G359.37+0.11 (RF-C11)** There are two sets of pair of filaments RF-C6 & RF-C7 as well as RF-C11 & C12 which appear to cross each other. The pair of RF-C6 and C7, as shown in Figure 11c and 12p, run perpendicular and parallel to the Galactic plane whereas RF-C11 and RF-C12, as labeled in Figure 11c, cross each other at a $60^0$ angle. RF-C7 in Figure 12p appears to show wiggles along its horizontal direction. The extension of RF-C12, as shown in Figure 11c, appears to terminate at the compact source G359.24+0.16. The full extent of RF-C12 extends for about 10' but the brightest portion has a length of $\sim 2'$ with a surface brightness of 1 mJy beam$^{-1}$. Although the brightness of faint emission between RF-C12 and G359.24+0.16 is at a level of background noise (0.1 mJy beam$^{-1}$), we believe that the faint portion of RF-C12 is a coherent structure and is an extension of the brightest portion of the filament.

**G359.37-0.03 (RF-C10)** Similar to G359.45-0.06 (RF-C1) and other filaments near Sgr C such as G359.59-0.17 (RF-C2), G359.34-0.15 (RF-C13) and G359.29+0.11 (RF-C15), G359.37-0.03 (RF-C10) appears to bend and join a diffuse source G359.36+0.0, as shown in Figure 12i. The faint diffuse emission at the terminus of G359.37-0.03 (RF-C10) resembles...
the HII region associated with G359.45-0.06 (NRF-C1).

**G359.32-0.06 (RF-C14)** Figure 11a and 12q show the appearance of a “bipolar” feature with a length of \( \approx 45\arcsec \) as it extends to the northeast and southwest. G359.32-0.06 (RF-C14) is identified as one of many linear features with a position angle ranging roughly between 30\(^0\) and 60\(^0\), as seen in Figure 11a. These filaments are grouped together running parallel to each other in the Galactic plane with similar orientations to the individual components of G359.49-0.12 (RF-C4). However, the filaments grouped together near G359.32-0.06 (RF-C14) appear to be broader and surrounded by diffuse extended features along the Galactic plane.

**Additional Filaments** Figures 12f–s show contour and grayscale images of a subset of linear filaments found in the vicinity of the Sgr C region. A variety of linear filaments designated as G359.37+0.11 (RF-C10), G359.41-0.26 (RF-C17), G359.35-0.24 (RF-C18), G358.98-0.25 (RF-C22), G359.48-0.23 (RF-C24), G359.70-0.28 (RF-C26), G359.30-0.06 (RF-C32) and G359.63+0.04 (RF-C33) are displayed in these figures (see Table 3). The brightness distribution of these filaments generally show knot-like structure with non-uniform surface brightness as seen in G359.1-0.2 or the Snake filament, as described below in more detail. Some of the filaments appear to terminate in the vicinity of a compact source such as RF-C24 in Figure 12h.

**G359.23-0.82 (the Mouse) and G359.28-0.26** Figure 13a shows contours of the nonthermal pulsar wind nebula G359.23-0.82 (Yusef-Zadeh and Bally 1992; Camilo et al. 2002) whereas Figure 13b displays a bright and extended cometary thermal source G359.28-0.26 (Uchida et al. 1992); This HII source has a bright counterpart in the *Midcourse Space Experiment* (MSX) 8\( \mu \)m image.

**G359.47+0.03 (RF-C28)** Figure 13c shows a number of HII regions in Sgr C. A compact HII feature G359.65-0.09 appears at the terminus of G359.47+0.03 (RF-C28), as seen Figure 13c.

**G359.1-0.2 (NRF-C19, the Snake)** The region to the southwest of Sgr C lies a prominent
nonthermal filamentary structure known as the Snake filament extending for more than 20′. Figure 11d shows this striking feature with its two prominent kinks near G359.13-0.20 and G359.12-0.26 (e.g., Gray et al. 1991, 1995). The northern extension of G359.16-0.04 coincides with a thermal source G359.16-0.04 (see also Figures 9a,b) whereas the southern end of the Snake appears to cross SNR G359.1-0.5 (Caswell and Haynes 1987; Uchida et al. 1996). The prominent HII region G359.16-0.04 is known to have a number of compact radio continuum sources (Uchida et al. 1996). Figures 12l,m show close-up views of two kinks noted along the length of the Snake. There are two compact sources G359.13-0.20 and G359.12-0.26 which are located within or in the vicinity of the region where the surface brightness of the Snake increases. The Snake is known to show a gradient in its spectral index at the location of the kinks (Gray et al. 1995). The spectral index along the NRFs is generally constant and flat between 6 and 20cm with the exception of the kink at G359.13-0.2 where the spectrum steepens to $\alpha=-0.5$. Subfilamentation has also been detected in the vicinity of the kinks (Gray et al. 1995). Similar to the Sgr C NRF (RF-C1 in Table 3), the Snake has a continuous structure but shows knotty appearance along its length. The brightest segments of the Snake are in the middle where the filaments are most curved. Like a number of long isolated linear filaments, the Snake is likely to be made up of a pair of filaments that run parallel to each other or is a hollow limb-brightened cylindrical structure. A more detailed study of this structure will be given elsewhere.

4.2. Sgr E (G358.7-0.0)

4.2.1. Large-scale View

High resolution radio continuum and radio recombination line observations of Sgr E, one of the least studied HII complexes in the Galactic center region, show that the distribution of the continuum emission is dominated by compact sources displaying thermal characteristics (Liszt 1992; Gray et al. 1993; Cram et al. 1996). Figures 14a,b show high and low-resolution 20cm
images of Sgr E, respectively. These images show a number of bright compact sources amounting to \(2 \times 10^3 \, M_\odot\) of ionized gas excited by about 20 OB stars (Gray et al. 1993). There are two linear filaments G358.62+0.07 (RF-E1) and G3558.79-0.13 (RF-E2) listed in Table 3. These filaments, which appear to have similar morphology to NRFs, are displayed in Figure 14a. There are other filamentary structures seen in this image and they are difficult to separate from thermal features associated with extended ionized shells in this HII complex.

The low-resolution image of Figure 14b shows a string of HII regions distributed on a partial ring; this distribution is reminiscent of HII regions seen in Sgr B2 and W49N (e.g., De Pree et al. 2000). We note a large-scale diffuse filamentary structure G358.60-0.27 (RF-E3) arising from the center of Sgr C. The closest source lying at one end of the filament is Sgr E53 at G358.3-0.12 (Gray et al. 1993). The nature of this new elongated feature (RF-E3 in Table 3) extending for about 20' is unknown. Its width is about 1' and its length is as long as the length of the Snake but its structure is highly distorted along its length. Similar to the Snake and Sgr C filaments, one end of G358.60-0.27 appears to terminate near the center of the Sgr E HII complex.

4.2.2. Individual Images

**G358.62+0.07 (RF-E1)** Figures 15a shows contour images of a filamentary structure RF-E1 (the “spoon” filament) with a position angle of 117°. This filament appears to be associated with a thermal source G358.63+0.06 which is designated as Sgr E19 by Cram et al. (1996). The width of this filament increases away from the direction of Sgr E19 along its ~ 100" extent. The morphology of the filament indicates that the filament is originated with the HII region.

Radio recombination line emission from this bright and compact source confirms its thermal nature but at a radial velocity near 0 km\(\text{s}^{-1}\) which is considerably different than the velocity of molecular and ionized gas associated with Sgr E (Cram et al. 1996). This is perhaps one of the best examples that a thermal source lies at the terminus of a filamentary structure. Similar to RF-C1 and its Sgr C HII region, high resolution image of the spoon filament
runs tangent to an asymmetric shell-like thermal source with an opening that is not aligned along the orientation of RF-E1. The integrated flux density of the compact source and the filament at 20cm are 409 and 36 mJy, respectively (see Table 3).

**G358.79-0.13 (RF-E2)** Figure 15b shows grayscale contours of the central region of Sgr E. Another filamentary feature RF-E2 or G358.79-0.13 is detected at the center of a diffuse circular feature. The diameter of this circular feature is $3.4'$ having surface brightness of $\approx 1$ mJy beam$^{-1}$. The morphology of RF-E2 is similar to RF-E1 in that the filament appears to join the bright thermal feature G358.72-0.12 (Cram et al. 1996). The position angle of RF-E2 is close to $97^{0}$. We note that a number of diffuse features in Sgr E are elongated in the direction approximately parallel to those of RF-E1 and E2.

### 4.3. The Radio Arc (G0.2-0.0) and its Extensions

G0.2-0.0 known as the radio continuum Arc is the prototype filamentary structure consisting of a network of vertical filaments with lengths of about 30 pc distributed symmetrically with respect to the Galactic equator (Yusef-Zadeh, Morris and Chance 1984; Yusef-Zadeh and Morris 1987a,b,c; Anantharamaiah et al. 1991). This region contains the largest concentration of long and bright NRFs as well as three prominent HII regions: G0.07+0.04 (the Arched filaments), G0.18-0.04 (the Sickle) and G0.16-0.06 (the Pistol). The nonthermal bundle of filaments, called RF-S0 in Table 3, cross all three HII regions, as labeled on Figure 16a. These HII regions are thought to be ionized by two massive clusters of hot stars known as the Arches and the Quintuplet clusters (e.g. Cotera et al. 1996; Serabyn, Shupe and Figer 1998; Figer et al. 2002). Additional curved structures, similar to the Arched filaments, though much fainter, are also detected on the negative latitude side of the linear filaments of the radio Arc. These curved structures appear to cross the nonthermal filaments near G0.16-0.15.

Like Sgr C and its extensions, the Arc and its extensions lie at the eastern “footprint” of the Galactic center lobe (Tsuboi et al. 1986). Two polarized lobes of emission are detected along
the extensions of the vertical filaments of the Arc away from the Galactic plane (Tsuboi et al. 1986). The vertical network of filaments in the Arc extend toward positive and negative latitudes $-0.75^0 < b < +0.75^0$ as the filaments become diffuse, and faint in their surface brightness (Sofue and Handa 1984). Here, we show 20cm images of the southern and northern extensions of the Arc.

4.3.1. The Southern Extension of G0.2-0.0

4.3.2. Large-scale View

Figures 16b,c show the grayscale continuum images of two overlapping $\lambda$20cm fields located along the southern extension of the Arc. The new filaments are labeled on this figure and their Galactic coordinates are listed under S. Arc in Table 3. A number of filaments to the south and southeast of the Arc has been recognized to have nonthermal characteristics based on single-dish polarization measurements (Tsuboi et al. 1986; Seiradakis et al. 1985) and 6cm VLA observations (Yusef-Zadeh 1986). The long filament G0.17-0.42 (RF-S5) becomes brightest in the middle and breaks up into two parallel filaments as they run toward negative latitudes. This filament appears to be distinct from the network of filaments associated with the Arc. The filament G0.11-0.40 (RF-S7) which is more diffuse and fainter than RF-S5 runs also in the same direction. A low-resolution version of RF-S5 and S7 in Figure 7a shows that these filaments coincide with the eastern and western edges of an elongated structure with a width of about 3' and a length of about 20' running perpendicular to the Galactic plane. There is clearly diffuse linearly polarized emission arising from the region between RF-S5 and RF-S7 as detected in the southern component of the Galactic center lobe (Seiradakis et al.1985; Tsuboi et al. 1986). The orientations of RF-S5 and S7 are tilted by about 20° with respect to the position angle of the network of filaments that comprise the Arc, as seen in Figure 16a.
4.3.3. Individual Images

G0.17-0.42 (RF-S5) Figures 17a,b show grayscale and contour images of RF-S5. We note a bright compact source G0.19-0.69 along the southern extension of RF-S5 in Figure 17b whereas a bow shock-like structure G0.13-0.28 is noted at the northern extension of RF-S5 in Figure 17a.

G0.13-0.58 (RF-S6) A new linear feature RF-S6 with its wiggly structure appears to cross RF-S5 in Figure 16b. The southwestern and northeastern extensions of this weak filamentary structure, as shown in Figure 17c, appear to be terminated at an unresolved compact source G0.08-0.61 at one end and an extended bright feature G0.28-0.48 at the other end, respectively. Because of the complex extended emission noted in this region, the weak distorted filament RF-S6 crossing RF-S5 needs to be confirmed in future observations. Figures 17d,e show two renditions of G0.28-0.48 with its core and a partial shell structure. A linear structure with an orientation parallel to the Galactic plane appears to be terminated at the core of G0.28-0.48.

G0.39-0.12 (RF-S2) Another filamentary structure whose northern and southern extensions terminate at a diffuse feature and a compact source is G0.39-0.12 (RF-S2). Figure 17f shows the compact source G0.42-0.32 and the diffuse feature G0.38+0.02; both these sources are aligned along the extensions of RF-S2. Similarly, G0.43-0.31 (RF-S1) consists of two parallel filaments whose northwestern extensions appear to terminate at two compact sources G0.32-0.19 and G0.32-0.2. A contour map of these compact sources is shown in Figure 17m.

G359.88-0.28 (RF-S9), G0.30-0.27 (RF-S3) Figures 17g-l show contour and grayscale representations of additional filaments found in the region south of the radio Arc. In particular, we note that G359.88-0.28 (RF-S9), as seen in Figures 17j and k, is a filamentary structure that appears to have a similar morphology to that of Sgr C where one end of the filament terminates at a thermal source G359.0–0.32. A higher resolution image of RF-S9 is displayed in Figure 17k. Another bundle of filaments G0.30-0.27 (RF-S3) can be seen in
Figures 16b and 17i where two pairs of filaments running parallel to each other. We also note additional isolated filament RF-S8 with an extent of $3.7^\prime$ in Figure 17l.

**G0.09-0.09 (RF-S10)** Figures 17n shows a relatively broad filament G0.09-0.09 running roughly perpendicular to the Galactic plane. This filament which was recently identified as G0.087-0.087 at 32 GHz is linearly polarized (Reich 2003) and is thought to lie at the western edge of a dense molecular cloud G0.13-0.13. The eastern and western edges of this molecular cloud show X-ray filamentary structure; these edges are thought to be signifying interaction sites of the molecular cloud G0.13-0.13 with the filaments of the Arc. The eastern side at molecular cloud at G0.13-0.12 and with G0.09-0.09 (RF-S10) lies on the western side of the cloud whereas the filaments at G359.0.08-0.09 lie at the eastern side of the cloud (Tsuboi, Ukita and Handa 1997; Yusef-Zadeh, Law and Wardle 2002). Figure 16a shows a dearth of continuum emission between RF-S10 and the network of the filaments of the Arc where the CS molecular cloud is distributed.

**G0.06-0.08 (RF-S11), G0.09-0.15 (RF-S12)** Two other linear filaments in the vicinity of RF-S10 are shown in Figures 17n through 17p. G0.06-0.08 appears to have the same orientation as RF-S10 but displaced about two arcminutes west of RF-S10. G0.09-0.15 is a faint filament with typical surface brightness of $1\text{ mJy beam}^{-1}$ and appears to cross the southern filaments of the Arc, as seen in Figure 16a. We also note an elongated compact source to the south of RF-S12 which is oriented in the same direction as that of RF-S12.

**G0.2-0.0 (NRFs-S0)** The nonthermal radio filaments of the Arc at G0.2-0.0 cross the Galactic plane where two prominent HII regions G0.18-0.04 (The Sickle nebula) and G0.16-0.06 (the Pistol nebula) are distributed. Figures 17q,r show high-resolution grayscale and contour images of the region where the filaments of RF-S0 cross these HII sources. Morphological arguments have been made previously that the HII regions and the nonthermal filaments are associated with each other (Yusef-Zadeh and Morris 1987b).
Figures 18a-f show grayscale contours of non-filamentary extended features distributed to the south of the radio Arc at G0.2-0.0; many of the individual features presented in these figures are also labeled in Figure 16b.

### 4.3.4. The Northern Extension of G0.2-0.0

#### 4.3.5. Large-scale View

Similar to its southern extension, the northern extension of the radio Arc near $l \sim 0.2^0$ lies within a large-scale diffuse structure running perpendicular to the Galactic plane (e.g. Tsuboi et al. 1986; Seiradakis et al. 1985). The extension of the NRFs of the Arc toward positive latitudes has been argued to be physically associated with a lobe of polarized emission (Yusef-Zadeh and Morris 1987c). This lobe is also identified as the eastern "leg" or "footprint" of the Galactic center lobe crossing the Galactic plane at $l \sim 0.2^0$ (Sofue and Handa 1984). Figure 19a shows a low-resolution image of the northern extension of the Arc as a group of NRFs, designated as RF-N1, appear to pass through G0.17+0.15 (Yusef-Zadeh and Morris 1988). We note G0.15+0.23 (RF-N1) and G0.08+0.15 (RF-N2) cross the thermal Arched filaments of the Arc G0.07+0.04. The Arched filaments H II complex is comprised of a series of curved, narrow ridges of radio emission which define the northern edge of the well-known Galactic center radio Arc (Yusef-Zadeh, Morris, & Chance 1984; Morris and Yusef-Zadeh 1989; Lang, Morris and Goss 2002). The Arched filaments extend for $9' \times 6'$ (or $23 \times 16$ pc at the Galactic center distance of 8.5 kpc) and are located $10'$ in projection from Sgr A*.

Figure 19b-d show high and low-resolution images of a number of filaments found at positive latitudes between $l \sim -0.5^0$ and $0.2^0$. The brightest segment of Sgr A, as shown in white in Figures 19b,c, is known as Sgr A East. A collection of broad linear features, aka the "streamers", appears to arise from Sgr A as it bends at positive galactic latitudes $b \sim 3'$. We note faint and narrow linear filaments G359.93+0.07 (RF-N6) running along the direction of the streamers. These new linear features as well as the streamers terminate within the ionized gas of Sgr A West which itself
is surrounded by the circumnuclear molecular ring. The Sgr A West HII region is known to be powered by the UV radiation from the IRS 16 young star cluster.

4.3.6. Individual Images

**G0.15+0.23 (RF-N1), G0.08+0.15 (RF-N2)** Figures 20a,b show contour and grayscale images of RF-N1 and RF-N2. The system of linear filaments in RF-N1 is most distorted as it crosses the shell-like structure G0.17+0.15 (Yusef-Zadeh and Morris 1988). The system of RF-N1 appears to be comprised of three distinct filaments, two of which surround an HII region G0.17+0.15. Like many filaments described above (e.g. RF-C1 and C4 of Sgr C in Figure 11a), these RFs also run along the edge of the shell-like thermal source G0.17+0.15. We believe the morphology of the filaments indicate strongly that these NRFs are interacting with G0.17+0.15 which is known to have an 8µm MSX counterpart.

Figure 20b shows a lobe of nonthermal diffuse emission detected to the north of N1 and N2. Polarization measurements of the lobe show that the magnetic field is oriented perpendicular to the Galactic plane similar to the orientation of the NRFs N1 and N2 (Tsuboi et al. 1986). Figure 20c shows the surface brightness of RF-N2 peaks in the middle as it curves toward higher latitudes before the filament becomes broader and more diffuse. The width of RF-N2 changes by about a factor of 2 as its surface brightness decreases by a factor of ≈5. This filament appears to terminate at the location where a compact source G0.12+0.32 is located, as seen in Figure 20a.

**G0.02+0.04 (RF-N3), G359.98+0.02 (RF-N4)** Figures 20d,e show detailed structures of two shell-like thermal sources G0.02+0.04 and G–0.012+0.12, aka H4 and H1, respectively (Yusef-Zadeh and Morris 1987; Zhao et al. 1993; Lang et al. 1999). These HII regions appears to lie at the terminus of two RFs N3 and N4. The incomplete shell-type HII region G0.02+0.04 has an opening along the direction of RF-N3 whereas RF-N4 appears to run along the bright edge of G–0.012+0.12. Similar to G0.117+0.15, the morphological
association of HII region/filament in G0.02+0.04 is compelling. Radio recombination line H110α emission has been detected from G0.02+0.04 showing a radial velocity of $-39 \text{ km s}^{-1}$ with low electron temperature of $3.5 \times 10^3 \text{ K}$.

**G359.96+0.09 (RF-N5), G359.93+0.07 (RF-N6)** A larger view of RFs N4, N5 and N6 can be viewed in Figure 20f where G359.96+0.09 (RF-N5) appears to cross the streamers of Sgr A West as well as G359.98+0.02 (RF-N4). G35996+0.09 consists of two parallel filaments, one of which continues to extend toward RF-N4. It is not clear if RF-N4 and RF-N5 are associated with each other.

**G359.79+0.17 (RF-N8), G359.88+0.20 (RF-N7)** Figures 20g-h show close-up grayscale images of G359.79+0.17 (RF-N8) and G359.88+0.20 (RF-N7). G359.79+0.17 comprises of multiple parallel filaments whose intensity peak at midpoint along its curved structure. The filaments appear to be separated from each other as they run toward southeast. The extension of the fainter filament to the southwest appears to terminate at a compact source G359.80+0.06.

The elongated structure of the bright source G359.87+0.18 in Figure 20h is an artifact of the distortion caused possibly by phase and amplitude errors. This source G359.87+0.18 is identified as an extragalactic FR II radio galaxy (Lazio et al. 1999). In spite of the errors affecting the appearance of G359.87+0.18, RF-N7 is clearly identified as an isolated linear radio filament adjacent to this source.

**G0.09-0.05 (RF-N9), G0.12-0.01 (RF-N13)** Figure 20i shows a close-up view of the Arched filaments with a resolution of $2.1'' \times 1.2''$. We note a linear filament RF-N9 with a position angle of $171^\circ$ originating from a diffuse feature G0.08+0.01, resembling a number of thermal ionized features associated with the Arched filaments. The faint linear filament with a surface brightness of 1-2 mJy beam$^{-1}$ extends for about 3’. Figure 20j shows contours of G0.08+0.01. Another weak linear structure G0.12-0.01 running almost parallel to the Galactic plane is detected in Figure 20i. The surface brightness of this feature G0.12-0.01 (RF-N13) is about 1 mJy beam$^{-1}$ as it extends for about 1’ with a position angle $90^\circ$. 
The extension of G0.09-0.05 to the south, as best seen in Figures 20k and 19c, terminates at a pair of compact sources at G0.08+0.09 and G0.08+0.09 having peak flux densities of 9.45 and 6.4 mJy beam\(^{-1}\), respectively. These high-resolution images clearly show that G0.08+0.15 (RF-N2) and G0.09-0.05 (RF-N9) are distinct from each other but both filaments have very similar orientations, as seen in Figures 20i,k. Although the extension of RF-N2 to the north is very prominent (see Figure 19a), its southern extension is faint in its surface brightness and appears to terminate at a bright compact source at G0.01-0.05 with a peak flux density of 14.9 mJy beam\(^{-1}\). We also note enhanced emission at the position of G0.08+0.02 along the extension of RF-N2, as seen in Figure 20i. RF-N2 crosses thermal Arched filaments, as seen in Figure 20j. There are other weak linear filaments that follow the orientation of the Arched filaments but are difficult to separate them from the bulk of thermal emission arising from the Arched filaments.

### 4.4. Sgr A (G0.0+0.0) and its Neighbors

#### 4.4.1. Large-scale View

Multi-wavelength observations of the Galactic center region shows a clumpy molecular ring with a scale of 2 to 5 pcs rotating around Sgr A\(^{*}\). The ring is heated by a centrally concentrated cluster of hot, young stars, the IRS 16 cluster, with similar characteristics to the Arches and the Quintuplet clusters. Within the ring’s central cavity, three “arms” of ionized gas (Sgr A West) are generally in orbital motion around the center. On a larger scale, a non-thermal structure (Sgr A East or SNR G0.0+0.0) is projected against Sgr A West and the molecular ring. Sgr A East is considered to be a shell-type supernova remnant. The Sgr A complex is comprised of both thermal Sgr A West and nonthermal Sgr A East as well as a halo of nonthermal gas enveloping both Sgr A East and West (e.g., Yusef-Zadeh and Morris 1987a; Pedlar et al. 1989).

Two other radio continuum sources that have thermal spectrum are G359.7-0.0 and G359.8-0.30, both of which are located in projection within the region between Sgr A and Sgr C.
A number of compact thermal sources have been detected in G359.7-0.0 (Liszt and Spiker 1995). Detailed radio continuum study of G359.8-0.30 has not been carried out previously. Low-resolution images, as seen in Figures 8a,b, show a large shell-like structure with a diameter of $\sim 10'$ centered roughly around G359.8-0.30. An 8$\mu$m MSX image of this region suggests that G359.8-0.30 has thermal characteristics.

4.4.2. Individual Images

G359.98-0.03 (RF-A7), G359.96-0.03 (RF-A10) Figure 21a shows a close-up view of the shell-type SNR G0.0+0.0 (Sgr A East) which is elongated along the Galactic plane. The three-armed spiral structure of Sgr A West G359.94-0.05 as well as a cluster of HII regions G359.98-0.07 distributed at the southeastern edge of Sgr A East are also noted. A number of straight and curved filamentary structures with a range angular sizes between 30$''$ to 1$'$ is detected throughout Sgr A East; The new filaments are labeled on Figure 21a. In particular, we note a number of filamentary features designated as G359.98-0.03 (RF-A7), G359.96-0.03 (RF-A10), G359.96-0.04 (RF-A11), G359.95-0.05 (RF-A12) and G359.96-0.05 (RF-A13). These filamentary structures (RFs A7, A10, A12 and A13) give the appearance of an elliptical shell with a diameter $2' \times 1'$ centered on G359.96-0.04.

Because of the wide range of angular scales of radio features found in the complex region surrounding Sgr A, we present a number of figures which are sensitive to bringing out features with scale lengths ranging between few arcseconds to few arcminutes, as displayed in Figures 21b,c,d. The large-scale “streamers” are noted to run toward more positive Galactic latitudes, as seen in Figures 21c,d. The base of the streamers terminate where the Sgr A West HII region lies. A different rendition of the Sgr A streamers designated as G359.93+0.07 (RF-N6) is also shown in Figures 19b,c and 20f. Like Sgr C and the radio Arc that show prominent vertical filaments away from the Galactic plane, Sgr A is also recognized to have a long, straight nonthermal filament G359.96+0.09 (RF-N5 in Figure 21d). G359.96+0.09 (aka "thread") appears to terminate near the eastern edge of the
streamers (Morris and Yusef-Zadeh 1985; Yusef-Zadeh and Morris 1987). G359.96+0.09 (RF-N5) extends for about ten arcminutes toward positive galactic latitudes. This filament is resolved into two subfilaments and becomes very faint compared to the bright shell-like HII regions distributed between the Arc and the Sgr A complex. G359.96+0.09 is brightest at its midpoint where the linear filamentary structure appears to deviate from a straight line as it breaks up into two components.

**G359.88-0.07 (RF-A4), G359.85-0.02 (RF-A6)** Figure 21d shows a number of filaments with different orientations and curvature. G359.88-0.07 (RF-A4) and G359.85-0.02 (RF-A6) run perpendicular and parallel to the Galactic plane. We also note G359.89-0.10 (RF-A3) consists of two components that deviate from a straight geometry.

**G359.78+0.01 (RF-A16), G359.73+0.02 (RF-A17)** In the region to the west of Sgr A where G359.7-0.0 HII complex lies, we find two faint filaments G359.78+0.01 (RF-A16) and G359.73+0.02 (RF-A17) running almost perpendicular to the Galactic plane. Figures 21d,e show these faint filaments. We note that the extensions of RF-A16, RF-A17 and G359.72+0.03 (RF-A18) terminate at three resolved features labeled as G359.79-0.04, G359.74-0.02 and G359.72-0.01, respectively.

**G359.72-0.50 (RF-A15), G359.68-0.39 (RF-A19)** The region to the southwest of Sgr A lies a large-scale diffuse structure G359.8-0.30 showing a number of diffuse and compact sources. Figures 21f through 21h show two different representations of G359.8-0.30 where we find a number of linear structures. In particular, a long linear structure G359.72-0.50 (RF-15) extending for about 15′ with a position angle of 59°, as listed in Table 3. G359.68-0.39 (RF-A19) is another long filament that runs perpendicular to the Galactic plane. Two diffuse blob-like structures G359.7-0.4 and G359.6-0.2 are surrounded by a number of linear structures RF-C2, RF-C26. RF-A19 and RF-A15.

Figures 22a-h display contour distribution of some of the filamentary structures found to the west of Sgr A, Sgr A East and G359.8-0.30. The filaments are oriented with a wide variety
of position angles with respect to the Galactic plane. Figure 22c show two linear filaments oriented parallel (RF-A6) and almost perpendicular (RF-A5) to the Galactic plane, respectively. Figures 22b,e show distorted filamentary structures (RFs A2, A3 and A8). Distorted filaments are generally characterized to have multiple components and are generally brighter than the surface brightness of single isolated filaments. For example, curved filaments RFs-A2, A3 in Figure 21b consist of multiple parallel components and appear to be brighter in their surface brightness than single filaments such RFs-A5, A6 and A9. Some filaments also show bow shock-like structures like the system of filaments identified as RF-A7 in Figures 21a and 22f. Lastly, we note that some of the filaments lie adjacent to compact sources. In particular, RF-A4 lies within 45" of two compact sources, G359.87-0.04 and G359.87-0.09 (Figure 22b). The latter source is known as a thermal source based on its flat spectrum (Ho et al. 1985) and is resolved into two components, as seen in Figure 22b.

Figures 23a-b show contour images of Sgr West and the well-known string of HII regions lying at the edge of Sgr A East. Another string of compact sources beyond the edge of Sgr A East is also presented in Figure 23c. The southern arm of the spiral-shaped ionized gas associated with Sgr A West (Figure 23a) near G356.17-0.05 shows a drop in its brightness distribution which is likely to be due to optical depth effect. Sgr A West is known to be optically thick at 327 MHz but this is the first evidence that similar effect has been detected at 20cm (a more detailed analysis will be given elsewhere).

4.5. Sgr B2 (G0.7-0.0) and its Neighbors

4.5.1. Large-scale View

Radio continuum observations of the well-known star forming region Sgr B show two major components Sgr B1 (G0.5-0.0), Sgr B2 (G0.7-0.0) and an intervening source G0.6-0.0 (e.g., Mehringer et al. 1992). Figure 24a shows a high resolution image revealing the large-scale distribution of all three components. Sharp semi-circular and bar-like ionization fronts are noted
in Sgr B1 whereas numerous ultracompact HII regions with cometary morphology dominate the emission in Sgr B2 and G0.6-0.0. Figure 24b, c show the same region as Figure 24a except that only the highest and lowest resolution data are used to construct the images, respectively. Two long isolated filaments G0.43+0.01 (RF-B1) and G0.39+0.05 (RF-B2) are revealed in the region to the west of Sgr B, as shown in Figures 24c,d. We also note a number of extended HII features north of G0.6-0.0 at b > 2'.

4.5.2. Individual Images

G0.43+0.01 (RF-B1), G0.39+0.05 (RF-B2) Two isolated filamentary structures, G0.43+0.01 (RF-B1) and G0.39+0.01 (RF-B2), are shown in Figure 24d. Unlike the bright filaments which deviate from straight line and show multiple filamentary structures with curved morphology, these thin, isolated, single filaments are faint with uniform surface brightness of about 1 mJy beam\(^{-1}\). We also note a semi-circular-shaped thermal feature G0.38-0.02 and two compact sources G0.41-0.02 and G0.42-0.06 distributed in the vicinity of the filaments. Neither of these compact sources are aligned with the extensions of the filaments to the south. However, it is possible that these images are not sensitive to the diffuse and faint segments of the filaments with surface brightness < 1 mJy beam\(^{-1}\) extending to the compact sources. There are examples of radio filaments such as RF-N8 in Figure 20g in which the filaments appear to bend close to a compact source. A third linear filament that has been identified previously in adjacent images is G0.39-0.12 (RF-S2) which extend for about 8' in the direction perpendicular to the Galactic plane. This filament is broader than RF-B1 and RF-B2 but shows the same orientation as the rest of filaments in Sgr B. The northern end of G0.39-0.12 appears to bend toward Sgr B1 before it dissapears in the bright continuum emission from Sgr B1.

There are a number of linear features detected throughout the Sgr B region whose continuum emission is dominated by a mixture of bright, compact, thermal sources and diffuse and extended
features. We believe that these features do not belong to the population of nonthermal radio filaments and they are likely to be thermal features associated with ionization fronts at the interface of the HII and molecular clouds. Figure 25a shows a contour image of the Sgr B region. Because of the large-extent and the complex structural details of Sgr B, grayscale images of several segments of the image are displayed followed by their contour representations. High-resolution image are divided into three sections; the grayscale and contour images of each of these segment are presented in Figures 25b-g.

4.6. Continuum Features at l > 0.7°

4.6.1. Supernova Remnants

Figure 26 shows a high-resolution mosaic image of the region between l ~ 1° and 5°. The continuum emission in this region is dominated by HII regions and SNRs. Figures 27a-d show four known SNRs G0.9+0.1, G1.4-0.1, G3.7-0.2 and G1.9+0.3 with new structural details (see Gray 1994a,b and the references therein).

SNR G0.9-0.1 SNR G0.9-0.1 appears to show a symmetrical linear feature, as seen in Figure 27a, arising from its center where the bright pulsar wind nebula lies (Helfand and Becker 1987). The northeastern half of this barrel-shaped SNR which is facing away from the Galactic plane is brightest. The HII region G0.83+0.19 to the north of G0.9+0.1 has a measured radial velocity of 9.7 kms$^{-1}$ (Kuchar & Clark 1997).

SNR G1.4-0.1 SNR G1.4-0.1 in Figure 27b shows a symmetrical shell structure with a number of compact sources projected against the remnant (see Table 4). The southern half of this remnant is thought to be interacting with a molecular cloud inferred from the detection of OH (1720 MHz) maser emission (Yusef-Zadeh et al. 1999; Bhatnagar 2002).

SNR G3.7-0.2 Figure 27c shows the northern half of another barrel-shaped SNR G3.7-0.2 whereas Figure 27d displays the crescent-shaped structure of SNR G1.9+0.3. The brightest
half of this shell-type remnant runs normal to the Galactic plane.

**SNR G1.0-0.1** Figure 27e shows a low-resolution image of SNR G1.0-0.1. This remnant which is also called Sgr D remnant has a barrel-shaped morphology with its northern half facing the Galactic plane; the eastern half near G1.16-0.23 shows diffuse extended structure which may be part of the remnant.

**Candidate SNR G1.0-0.1** A candidate SNR G3.7-0.1 is resolved into four components, as shown in Figure 27f; two of the brightest components are G3.67-0.1 and G3.66-0.1. Bhatnagar (2000) has recently modeled the continuum spectrum as a combination of thermal and nonthermal emission. If the spectrum contains nonthermal emission, the shell-like morphology of G3.66-0.1 is consistent with being a supernova remnant. A hydrogen-recombination line velocity of $3\text{ km}\cdot\text{s}^{-1}$ based on low spatial resolution observations has been measured toward G3.66-0.12 (Caswell & Haynes 1987).

4.6.2. **Diffuse Thermal Sources**

High-resolution radio continuum images do not show any evidence of linear filaments beyond Sgr B with the exception of one possible source G1.3+0.1. This source, as shown in Figure 28a, consists of two shell-like features that appear to be in contact with each other. A linear feature with an extent of about $4'$ and width of $45''$ appears to arise from the location where the two incomplete shells meet. The linear feature appears broader than typical radio filaments, as catalogued in Table 3. The largest concentration of NRFs and RFs found in this survey are detected mainly within the region confined by the Galactic center lobes. Other examples of shell-like or cometary HII features are presented in Figures 28b-c. Figures 28d,e show two extended HII complexes G4.57-0.12 and G4.42+0.12 (Lockman et al. 1989). The thermal source G4.57-0.12 in Figure 28d shows an extended triple component $6'$ in extent. A hydrogen-recombination line velocity of $+18\text{ km}\cdot\text{s}^{-1}$ has been measured (Caswell and Haynes 1987). G4.27+0.04 in Figure 28f is resolved into a shell and a compact source with a diameter of $\sim 2'$ (Bhatnagar 2002). Radial
velocity measurement of HII region G2.51-0.03, as seen in Figure 28m, indicates a velocity of 8.3 \( \text{km s}^{-1} \) (Lockman, et al. 1996). A number of other extended, thermal features are noted between G0.7-0.0 and G4.5+0.0 as their grayscale representations are displayed in Figures 28g-n.

5. Discussion

The present 20cm survey has provided a great deal of information on the structural details of HII regions, compact sources, nonthermal filaments and supernova remnants in the complex region of the Galactic center. Future multi-wavelength study of these features should further our understanding of these objects. In addition, the present survey reports a catalog of more than 80 system of filamentary structures, many of which remain as candidate nonthermal filaments. All the new filaments are distributed in the region between Sgr B1 (G0.5-0.0) and Sgr E (G358.7-0.0). It is likely that additional system of filaments could be uncovered with observations having higher sensitivity, a more uniform \( uv \) coverage and a larger spatial coverage at higher galactic latitudes. A wide range of morphological details are detected among the linear filaments. Some appear as a single, faint, straight and isolated filament with a surface brightness of 1 mJy beam\(^{-1}\) and others appear as bright network of two or more curved filaments running parallel to each other. The largest concentration of filaments are characterized in pairs separated between few arcseconds to 30\( '' \) from each other as they run parallel to each other. It is not clear if the pair of closely spaced narrow filaments signify two distinct parallel filaments or a single limb-brightened filament. We also note that some filaments break up into multiple subfilaments when they are most distorted (e.g., kinks). Some filaments show a curvature along their lengths as their brightness peak in midpoints as they gently curve.

Most of the new linear filaments reported here are likely to be of the population of radio filaments known to have nonthermal characteristics as recent 327 MHz and 6cm polarization measurements indicate. Some of the 20cm linear filaments reported here are also found independently at 327 MHz (LaRosa et al. 2004; Nord et al. 2004). Future polarization and spectral index measurements should confirm the nonthermal characteristics of the new filaments.
listed in Table 3.

Unlike earlier studies indicating bright filaments are continuous and generally running perpendicular to the Galactic plane, we note a large fraction of the filaments showing knot-like structure with gaps in between and the presence of a wide range of orientations with respect to the Galactic plane. We note several linear filaments parallel to the Galactic plane similar to G358.85+0.47 (Lang et al. 1999) which was discovered as the first filament not being perpendicular to the Galactic plane. Figure 29 shows a schematic diagram of the distribution of the filaments found in this survey. It is clear that the longest filaments roughly perpendicular to the Galactic plane. Unlike the most prominent long filaments with an extent > 5', the short filaments do not show a preferred orientation perpendicular to the Galactic plane. The wide range of orientations of the linear filaments provide strong observational constraints on the hypothesis that there is a large-scale poloidal magnetic field threaded in the Galactic center region. Assuming that the short filaments are nonthermal, these observation are not inconsistent with models that argue the origin of the magnetic field is local and dynamic (e.g., LaRosa, Lazio and Kassim 2001; Yusef-Zadeh 2003).

We also find that a number of filaments appear to terminate at an extended thermal source. In some cases, the linear filaments appear to run tangential to the edge of thermal sources or arise directly from a shell-like HII region (e.g., G0.02+0.04 (RF-N3) in Figure 20d). The physical relationship between diffuse thermal sources and the filaments need to be tested with additional observations. However, if such a relationship exists based on morphological grounds, then we argue that the origin of the filaments is in the prominent Galactic center star forming regions. It is not a coincident that the largest concentration of the filaments are populated in star forming regions in the Galactic center region. Recent interpretation of the origin of the filaments considers a mechanism in which the collective winds of massive WR and OB stars within a dense stellar environment produce nonthermal particles (Rosner and Bodo 1996; Yusef-Zadeh 2003). In the context of this model, HII regions which are associated with radio filaments are ionized by the young cluster of stars. Furthermore, we speculate that the low electron temperature measured
toward some HII regions in the Galactic center region might be explained by the contribution of nonthermal continuum emission which results a low estimate of the line-to-continuum ratio. Also, unusual kinematics of some of the HII regions may be explained by the dynamical interaction of supersonic motion of nonthermal filaments with HII regions.

We also note that compact radio sources are found along the extension of the terminus of a large number of filaments. If these compact sources are associated with the filaments, they may act as a hot spot in the context of a jet model where the supersonic motion of a jet-like filament is impacting the ISM. (Yusef-Zadeh and Königl 2004). The present survey shows that linear filaments have morphological characteristics similar to extragalactic FR I jets. Future high resolution and proper motion study of these compact sources should be able to test the jet model.

Lastly, since the “footprints” of the eastern and western lobes lie on two prominent sources with a large number of filaments, as seen in Sgr C and the Arc, the role and the relationship of the large-scale lobes should be tied to the origin of the nonthermal filaments. It is striking to note that very few filamentary structures are found beyond the edges of the footprints of the Galactic center lobe. It is possible the winds from clustered star formation in a star burst environment are responsible for the origin of the filaments as well as the lobes (Bland-Hawthorn and Cohen 2003; Law et al. 2004).

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Fig. 1.— (a) A diagram showing the number of VLA antenna pointings numbered in the order of decreasing Galactic longitude are used in this low-resolution (30′′) λ20cm survey. Fields A, B, C, D and E correspond to a number of overlapping pointings. (b) is similar to (a) except that the antenna pointings are based on high-resolution (10′′) observations. Overlapping pointings are represented by fields A, B and C and are shown in light gray.
Fig. 2.— (a) A mosaic image of the entire surveyed region at $\lambda 20$cm with a resolution of 30$''$. The logarithmic grayscale range is between 30.0 100.0 mJy beam$^{-1}$. (b) A close-up view of the brightest region toward Sgr A. Prominent nonthermal radio filaments (NRFs), SNRs and HII regions are designated.

Fig. 3.— (a) A first segment of the mosaic image is shown with a spatial resolution of FWHM=30$''$ x 30$''$. (b) The corresponding contours are drawn with levels set at 35, 40, 45, 55, 70, 100, 150 and 250 mJy beam$^{-1}$. The dotted line near 3$^0 20'$, 00 15' is an artifact of mosaicing.

Fig. 4.— (a) A second segment of the mosaic image is shown with a spatial resolution of FWHM=30$''$ x 30$''$. (b) The corresponding contours are drawn with levels set at 34, 37, 40, 43, 46, 50, 56, 64, 80 mJy beam$^{-1}$.

Fig. 5.— (a) A third segment of the mosaic image is shown with a spatial resolution of FWHM=30$''$ x 30$''$. There was a small overlap between pointing number 9 and A, as shown in Figure 1a, thus the mosaic image has cut off the region with a high noise level due to the primary beam correction. (b) The corresponding contours are drawn with levels set at 46, 52, 58, 64, 70, 76, 82, 90, 120, 155, 230 and 600 mJy beam$^{-1}$.

Fig. 6.— (a) A fourth segment of the mosaic image is shown with a spatial resolution of FWHM=30$''$ x 30$''$. (b) The corresponding contours are drawn with levels set at 40, 45, 50, 60, 70, 80, 90, 100, 130, 160, 200, 250, 300, 400, 600, 1000, 2000, 4000 and 8000 mJy beam$^{-1}$.

Fig. 7.— (a) A fifth segment of the mosaic image is shown with a spatial resolution of FWHM=30$''$ x 30$''$. (b) The corresponding contours are drawn with levels set at 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 110, 130, 160, 200, 240, 320 and 500 mJy beam$^{-1}$.
Fig. 8.— (a) A sixth segment of the mosaic image is shown with a spatial resolution of FWHM=30′′ × 30′′. (b) The corresponding contours are drawn with levels set at 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 120, 140, 160 and 180 mJy beam$^{-1}$.

Fig. 9.— (a) A seventh segment of the mosaic image is shown with a spatial resolution of FWHM=30′′ × 30′′. (b) The corresponding contours are drawn with levels set at 45, 50, 55, 60, 65, 70, 75, 80, 90, 100, 110, 120, 140, 160, 180, 220, 300, 400 and 500 mJy beam$^{-1}$.

Fig. 10.— (a) An eighth segment of the mosaic image is shown with a spatial resolution of FWHM=30′′ × 30′′. (b) The corresponding contours are drawn with levels set at 40, 42, 46, 48, 50, 54, 58, 62, 66, 70, 75, 80, 90, 110 and 160 mJy beam$^{-1}$. 
Fig. 11.— (a) A grayscale distribution of Sgr C with a resolution of $8.1'' \times 3.3''$ (PA=$-11^0$). The coordinates of the labeled radio filaments are listed in Table 3. RFs in this region are labeled. (b) The greyscale image of the southern extent of Sgr C where several newly identified RFs are found. This image is based only on the B-array configuration data with a resolution of $8.5'' \times 3.5''$ (PA=$-12^0$). (c) The grayscale image of the region to the north of Sgr C where the prominent G359.54+0.18 (RF-C3) lies, also known as the ripple filament. The resolution of this image is $10.1'' \times 8.3''$ (PA=$64^0$). (d) The region to the southwest of Sgr C lies the Snake or G359.1-0.2 with a resolution of $12.1'' \times 6.8''$ (PA=$52^0$). (e) The southern extension of the Snake filament G359.1-0.2 as well as two shell-type SNRs G359.1-0.5, G359.0-0.9 and the Mouse G359.23-0.82 are shown with a resolution of $12.8'' \times 8.4''$ (PA=$56^0$).
Fig. 12.— (a-b) Grayscale and contour images, respectively, of the brightest region of Sgr C with contours set at -0.25, 0.25, 0.5, 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 mJy beam$^{-1}$ with a resolution of 8.1$''$ × 3.3$''$ (PA=-11$^0$) and a greyscale flux range between -4 and 20 mJy beam$^{-1}$; (c) Greyscale contours of RF-C1, C5, C8, C10, C11, and C12 at 1, 1.5, 2, 3, 4, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, and 100 mJy beam$^{-1}$ with a resolution of 8.1$''$ × 3.3$''$ (PA=-11$^0$) and a greyscale flux range between -1 and 10 mJy beam$^{-1}$; (d) Grayscale contours of RF-C4 with contours similar to (c); (e) Contours of RF-C13 with contours similar to (c) but and a greyscale flux range between -0.5 and 2 mJy beam$^{-1}$; (f) Contours of RF-C18, C17 with levels 0.25, 0.5, 1, 1.5, 2, 3, 4, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, and 100 mJy beam$^{-1}$ and and a greyscale flux range between -0.4 and 4 mJy beam$^{-1}$; (g) Contours of RF-C2 with levels -0.5, 0.5, 0.75, 1, 1.25, 1.5, 2, 2.5, and 3 mJy beam$^{-1}$ and a greyscale flux range between -1.9 and 5 mJy beam$^{-1}$; (h) Contour levels .75, 1, 1.25, 1.5, 2, 3, 4, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, and 100 mJy beam$^{-1}$ and a greyscale flux range between -0.1 and 2 mJy beam$^{-1}$; (i) Contours of RF-C10 with levels .75, 1, 1.25, 1.5, 2, 3, 4, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, and 100 mJy beam$^{-1}$ and a greyscale flux range between -0.1 and 4 mJy beam$^{-1}$; (j) Contour levels 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 10, 15, 20, 25, 30, 35, 40, and 50 mJy beam$^{-1}$ and a greyscale flux range between -1 and 4 mJy beam$^{-1}$; (k) Contours of RF-C26 with levels -1, 1, 1.5, 2, 2.5, 3, 4, 5, and 6 mJy beam$^{-1}$ and a greyscale flux range between -3 and 15 mJy beam$^{-1}$; (l) The southern kink of the Snake with a resolution of 112.1$''$ × 6.8$''$ (PA=52$^0$) and contours set at -0.5, 0.5, 1, 1.5, 2, 3, 4, 5, 6, 7, 8, 10, 15, 20, 25, 30, 35, 40, 50 mJy beam$^{-1}$ and a greyscale flux range between -2 and 6.6 mJy beam$^{-1}$; (m) The northern kink of the Snake with contour levels set at -0.5, 0.5, 1, 1.5, 2, 3, 4, 5, 6, 7, 8, 10, 15, 20, 25, 30, 35, 40, 50 mJy beam$^{-1}$ and a greyscale flux range between -1 and 6.6 mJy beam$^{-1}$; (n) Contours at 2, 4, 10, 30, 40 mJy beam$^{-1}$ and a greyscale flux range between -1 and 3 mJy beam$^{-1}$; (o) Contours of RF-C18 with levels -0.5, 0.5, 0.75, 1, 1.25, 1.5, 2, 2.5, and 3 mJy beam$^{-1}$ and a greyscale flux range between -3 and 15 mJy beam$^{-1}$; (p) Contours of RF-C6 and C7 with levels 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 7, 8, 10, 12, and 14 mJy beam$^{-1}$ and a greyscale flux range between -1 and 20 mJy beam$^{-1}$; (q) Contours of RF-C14 with levels -1, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 8, and 10 mJy beam$^{-1}$ and a greyscale flux range between -1 and 12 mJy beam$^{-1}$; (r) Contour levels of -1.5, 1.5, 2, 2.5, 3, 4, 5, and 6 mJy beam$^{-1}$ and a greyscale flux range between -1 and 8 mJy beam$^{-1}$; (s) Contour levels of -0.5, 0.5, 1 and 1.5 mJy beam$^{-1}$ and a greyscale flux range between -44 and 297.9 mJy beam$^{-1}$
Fig. 13.— (a) Contours of emission from the Mouse G359.23-0.82 are set at -0.5, .5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 13, 15, 20, 25, 30, 40, 50, 60, 70 and 90 mJy beam$^{-1}$ and a greyscale flux range between -2.7 and 100 mJy beam$^{-1}$; (b) grayscale image of G359.28-0.26 with contours -0.5, .5, 1, 1.5, 2, 3, 4, 5, 6, 7, 8, 10, 15, 20, 25, 30, 35, 40 and 50 mJy beam$^{-1}$ and a greyscale flux range between -1.67 and 60 mJy beam$^{-1}$; (c) Contours of RF-C25 with levels 1, 1.5, 2, 4, 5, 10, 14, 20, and 26 mJy beam$^{-1}$ and a greyscale flux range between -5 and 15 mJy beam$^{-1}$; (d) Contours of RF-C21 and C19 with levels 0.5, 1, 1.5, 2, 3, 4, 6, 8, 10, and 12 mJy beam$^{-1}$ and a greyscale flux range between -1.7 and 13 mJy beam$^{-1}$. Extended emission from G359.16-0.04 is found at the terminus of the Snake (C19).

Fig. 14.— (a) A mosaic image of Sgr E showing the distribution of HII regions in this nebula with a resolution of 11.3$''$×7.9$''$ (PA=54$^0$); (b) a grayscale image of the central region of Sgr E with a resolution of 30$''$×30$''$.

Fig. 15.— (a) Contours of 20cm emission from RF-E1 set at 0.5, 1, 2, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70 and 90 mJy beam$^{-1}$ with a resolution of 11.3$''$×7.9$''$ (PA=54$^0$) and a greyscale flux range between -1.7 and 10 mJy beam$^{-1}$; (b) a larger view of Sgr E and RF-E2 with contours similar to (a) and a greyscale flux range between -9 and 5 mJy beam$^{-1}$.

Fig. 16.— (a) The vertical filaments (RF-S0) and the curved HII regions (i.e. the Arched filaments, the Sickle and the Pistol) comprise the Radio Arc at G0.2-0.0; the resolution is 12$''$×11$''$. The straight line at the bottom of the image is an artifact resulting from combing two adjacent fields. (b) The region to the south of the radio Arc showing filamentary structure in the southern lobe. The uv data $> 0.4k\lambda$ is selected. The resolution is 12.9$''$×9.2$''$ (PA=73$^0$); (c) A second field in the southern lobe with a resolution of 10.9$''$×8.7$''$ (PA=87$^0$).
Fig. 17.— (a) A 20cm image of the southern extension of the radio Arc with $12'' \times 9.4''$ (PA=64°); (b) Contours at -2, 2, 3, 4, 5, 6, 7, 8, 9, and 10 mJy beam$^{-1}$ and a greyscale flux range between -3 and 10 mJy beam$^{-1}$. RF-S6 can be seen clearly in Figure 16a; (c) Contours at -2, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14, 16, 20, 25, and 30 mJy beam$^{-1}$ and a greyscale flux range between -3 and 6 mJy beam$^{-1}$; (d) Grayscale image with a resolution of $7.76'' \times 6.3''$ (PA=66°). The data includes DnC, CnB and BnA-array data; (e) Similar to (d) but contours are shown at 2, 4, 6, 8, 10, 15, 20, 25, 30, 40, and 50 mJy beam$^{-1}$ and a greyscale flux range between -1.2 and 10 mJy beam$^{-1}$; (f) Sources G0.38+0.02 and G0.42-0.32 can be noted along the extensions of RF-S2 (g) Contours at -3, 3, 4, 5, 6, 7, 8, and 10 mJy beam$^{-1}$ with the same resolution of (a) and a greyscale flux range between -5 and 20 mJy beam$^{-1}$ (h) Contours at -2, 2, 4, 6, 10, 14, 18, 22, 30, 40, 50, 60, 80, and 100 mJy beam$^{-1}$ and a greyscale flux range between -5 and 20 mJy beam$^{-1}$; (i) Contours at -2, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14, 16, 20, 25, and 30 mJy beam$^{-1}$ and a greyscale flux range between -5 and 15 mJy beam$^{-1}$; (j) Contours at -6, 6, 9, 12, 15, 18, 21, 24, 30, 36, 42, 48, 60, 75, and 90 mJy beam$^{-1}$ and a greyscale flux range between -3 and 20 mJy beam$^{-1}$; (k-l) Grayscale images with a resolution of $10.7'' \times 7.7''$ (PA=70°); (l7m) Contours at -4, -3, 2, 3, 4, 5, 10, 15, 20, 30, 40 and 50 mJy beam$^{-1}$ and a greyscale flux range between -10 and 50 mJy beam$^{-1}$; (l7n) Contours at 15, 20, 25, 30, 35, 40, 50, 60, 70, 80, and 100 mJy beam$^{-1}$ and a greyscale flux range between -17.8 and 50 mJy beam$^{-1}$; (l7o) Greyscale image with a resolution of $3.5'' \times 2.9''$ (PA=26°); (l7p) Contours at 2, 3, 4, 5, 6, and 8 mJy beam$^{-1}$ and a greyscale flux range between -2 and 6 mJy beam$^{-1}$; (l7q) Greyscale image with a resolution of $2.1'' \times 1.2''$ (PA=8°); (l7r) Contours at 0.5, 1, 2, 3, 4, 5, and 6 mJy beam$^{-1}$ and a greyscale flux range between -0.5 and 3 mJy beam$^{-1}$.
Fig. 18.— (a) Contours at -1, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 20, 25, 30, 35, 40, 50, 60, and 70 mJy beam$^{-1}$ and a greyscale flux range between -3 and 10 mJy beam$^{-1}$; (b) Contours at -5, 2.5, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, and 80 mJy beam$^{-1}$ and a greyscale flux range between -10 and 50 mJy beam$^{-1}$. (c) Contours at -1, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 20, 25, 30, 35, 40, 50, 60, 70, and 90 mJy beam$^{-1}$ and a greyscale flux range between -1 and 25 mJy beam$^{-1}$; (d) Contours at -1, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, and 12 mJy beam$^{-1}$ and a greyscale flux range between -0.3 and 8.9 mJy beam$^{-1}$. (e) Contours at -1, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 20, 25, 30, 35, 40, 50, 60, 70, and 90 mJy beam$^{-1}$ and a greyscale flux range between -1.6 and 10 mJy beam$^{-1}$; (f) Contours at -3, 3, 4, 5, 7, 9, 11, 13, 15, 20, 25, 30, 40, and 50 mJy beam$^{-1}$ and a greyscale flux range between -10 and 60 mJy beam$^{-1}$. The resolution for (a-e) is 10.6$''$ × 9.3$''$ (PA=9$^0$) whereas for (f) is 10.3$''$ × 8.5$''$ (PA=-80$^0$)

Fig. 19.— (a-d) Grayscale images with a resolution of 30$''$ × 30$''$, 3.5$''$ × 3.2$''$ (PA=48$^0$), 3.76$''$ × 3.21$''$ (PA=67$^0$), 30.2$''$ × 25.3$''$ (PA=62$^0$), respectively
Fig. 20.— (a) Contours at -22.5, -17.5, -12.5, -7.5, -2.5, 2.5, 7.5, 12.5, 17.5, 22.5, 27.5, 37.5, 50, 62.5, 75, 100, 125, 150, 175, 200, and 225 mJy beam$^{-1}$ and a greyscale flux range between -100 and 300 mJy beam$^{-1}$. (b) A grayscale image with a resolution of 30$''$ × 15$''$ (PA=0$^0$); (c) Contours at 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 24, and 28 mJy beam$^{-1}$ with a resolution of 7.3$''$ × 6.7$''$ (PA=19$^0$) and a greyscale flux range between -6 and 20 mJy beam$^{-1}$; (d) Contours at 2.5, 5, 10, 15, 20, 25, 35, 45, 55, 65, 75, 85, 95, 105, 125, 150, 175, and 200 mJy beam$^{-1}$ and a greyscale flux range between -3 and 6 mJy beam$^{-1}$; (e) Contours at 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 17, 19, 21, 25, 30, 35, 40, 50, and 60 mJy beam$^{-1}$ with a resolution of 3.8$''$ × 2.8$''$ (PA=72$^0$) and a greyscale flux range between -3 and 10 mJy beam$^{-1}$; (f) Grayscale image with a resolution of 3.8$''$ × 2.8$''$ (PA=72$^0$); (g) Contours at -0.5, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 13, 16, 19, 22, 25, and 30 mJy beam$^{-1}$ with a resolution of 7.3$''$ × 6.7$''$ (PA=19$^0$) and a greyscale flux range between -5 and 10 mJy beam$^{-1}$; (h) Contours at 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 13, 16, 19, 22, 25, and 30 mJy beam$^{-1}$ with a resolution of 7.3$''$ × 6.7$''$ (PA=19$^0$) and a greyscale flux range between -2.1 and 5 mJy beam$^{-1}$; (i) Grayscale image with a resolution of 6.9$''$ × 6.4$''$ (PA=15$^0$); (j) Contours at 2, 3, 4, 5, 6, and 8 mJy beam$^{-1}$ and a greyscale flux range between -1.5 and 3 mJy beam$^{-1}$; (k) Grayscale image with a resolution of 2.1$''$ × 1.2$''$ (PA=8$^0$)

Fig. 21.— (a-e) Grayscale images of Sgr A with a resolution of 2.2$''$ × 1$''$ (PA=9.7$^0$) based only on the A-array data, 3.5$''$ × 2.9$''$ (PA=26$^0$) using the uv range of between 3 and 50kλ of the A-array data, 3.5$''$ × 2.9$''$ (PA=26$^0$) using the combined A, B, C and D-array data, 10.7$''$ × 7.7$''$ (PA=70$^0$) and 0.7$''$ × 7.7$''$ (PA=70$^0$), respectively; (f-g) Grayscale images of the region between Sgr A and Sgr C with a resolution of 11.9$''$ × 8.9$''$ (PA=59$^0$)
Fig. 22.— (a) Contours at -5, 5, 7, 9, 11, 15, 20, 25, 30, 40, 60, 80, 100, 150, 200, 300, 500, 700 and 900 mJy beam$^{-1}$ with a resolution of 10.7$''$ × 7.7$''$ (PA=70$^0$) and a greyscale flux range between -19 and 100 mJy beam$^{-1}$; (b) Contours at -4, 4, 5, 6, 7, 8, 10, 14, 18, 22, 30, 40, 50, 60, 70, 80, 100, 120, 140, 160, 180 and 200 mJy beam$^{-1}$ with a resolution of 3.5$''$ × 2.9$''$ (PA=26$^0$) and a greyscale flux range between -3.9 and 45 mJy beam$^{-1}$; (c) Contours at -2, 2, 2.5, 3.5, 4, 5, 7, 9, and 11 mJy beam$^{-1}$ with a resolution of 3.5$''$ × 2.9$''$ (PA=26$^0$) and a greyscale flux range between 0.35 and 19.34 mJy beam$^{-1}$; (d) Contours at -4, 4, 5, 6, 7, 8, 10, 14, 18, 22, 30, 40, 50, 60, 70, 80, 100, 120, 140, 160, 180, and 200 mJy beam$^{-1}$ with a resolution of 3.5$''$ × 2.9$''$ (PA=26$^0$) and a greyscale flux range between -1.2 and 18.6 mJy beam$^{-1}$; (e) Contours at -5, 5, 6.25, 7.5, 8.75, 10, 12.5, 17.5, 22.5, and 37.50 mJy beam$^{-1}$ with a resolution of 3.5$''$ × 2.9$''$ (PA=26$^0$) and a greyscale flux range between 0.35 and 19.34 mJy beam$^{-1}$; (f) Contours at 0.5, 1.5, 2.5, 3.5, 5, 6.5, 8, 10, and 12 mJy beam$^{-1}$ with a resolution of 2.2$''$ × 1$''$ (PA=9.7$^0$) and a greyscale flux range between -5.6 and 20 mJy beam$^{-1}$; (g) Contours at 0.25, 0.75, 1.25, 1.75, 2.5, 3.25, 4, 5, 6, 7.5 and 10 mJy beam$^{-1}$ with a resolution of 2.2$''$ × 1$''$ (PA=9.7$^0$) and a greyscale flux range between -3 and 14 mJy beam$^{-1}$; (h) Contours at 2, 3, 4, 7, 10, 15, 20, and 25 mJy beam$^{-1}$ and a greyscale flux range between -3 and 5 mJy beam$^{-1}$.

Fig. 23.— (a) Contours at 0.5, 1, 2, 4, 6, 8, 10, 12, 14, 16, 19, 20, 30, 40 and 50 mJy beam$^{-1}$ and a greyscale flux range between -5 and 10 mJy beam$^{-1}$; (b) Contours at 2, 3, 4, 5, 6, and 7 mJy beam$^{-1}$ and a greyscale flux range between -2 and 15 mJy beam$^{-1}$; (c) Contours at -2, 2, 2.5, 3, 3.5, 4, 5, 7, 9, and 11 mJy beam$^{-1}$; the resolution of all images is 2.2$''$ × 1$''$ (PA=9.7$^0$) and a greyscale flux range between -1.4 and 15.7 mJy beam$^{-1}$.

Fig. 24.— (a) grayscale image of Sgr B with a resolution of 2.52$''$ × 1.7$''$ (PA=21$^0$) based on combining BnA, C and D-array data using the masking technique; The same region as (a) except that only BnA-array data is used having the same resolution; (c) only C and D array data used with a resolution of 18×18$''$; (d) similar to (a).
Fig. 25.— (a) Contours at 3.5, 7, 10.5, 14, 21, 28, 35, 49, 63, 77, 105, 140, 175, 210, 280 and 350 mJy beam$^{-1}$ with the same resolution as Figure 24c and a greyscale flux range between -16 and 500 mJy beam$^{-1}$; (b-c) A grayscale image and contours at 1, 3, 5, 7, 9, 11, 15, 20, 25, 30, 40, 50, 70, 90 and 110 mJy beam$^{-1}$; (d-e) A grayscale image and its contours at 1.5, 2.5, 3.5, 4.5, 5.5, 7.5, 10, 12.5, 15, 20, 25, 35, 45 and 55 mJy beam$^{-1}$; (f-g) A grayscale image and its contours at 1.5, 2.5, 3.5, 4.5, 5.5, 7.5, 10, 12.5, 15, 20, 25, 35, 45 and 55 mJy beam$^{-1}$. The resolution of (b) to (e) is the same as Figure 24b.

Fig. 26.— A high resolution mosaic image of eight 20cm fields with a resolution of 10$''$ × 10$''$

Fig. 27.— (a) Contours of SNR G0.9+0.1 with levels at 2.5, 5, 7.5, 10, 15, 20, 25, 35, 45, 55, 75, 100, 125, and 150 mJy beam$^{-1}$. The beam size is 11.3$''$ × 8.6$''$ (PA=-74$^0$) and a greyscale flux range between -5 and 25 mJy beam$^{-1}$; (b) Contours of SNR G1.4-0.1 with levels at 0.75, 1.5, 2.25, 3, 4.5, 6, 7.5, 10.5, 13.5, 16.5, 22.5, 30, 37.5, and 45 mJy beam$^{-1}$ The beam size is 12.2$''$ × 8.2$''$ (PA=65$^0$) and a greyscale flux range between -1 and 3 mJy beam$^{-1}$; (c) Contours of the northern shell of SNR G3.7-0.2 with levels at 0.5, 1, 1.5, 2, and 3 mJy beam$^{-1}$ and a greyscale flux range between -0.5 and 3 mJy beam$^{-1}$. The beam size is 11.4$''$ × 8.4$''$ (PA=-84$^0$); (d) Contours of SNR G1.9+0.3 with levels at 1, 2, 3, 4, 6, 8, 10, 12, 14, 18, 22, 30, 40, 50 and 60 mJy beam$^{-1}$ The beam size is 12$''$ × 8.3$''$ (PA=-62$^0$) and a greyscale flux range between -2 and 50 mJy beam$^{-1}$; (e) Contours of Sgr D SNR with levels at 9, 12, 15, 18, 21, 24, 27, 30, 35, 40, 45, 50, 60, 70)×2 mJy beam$^{-1}$ with a resolution of 30×30$''$ and a greyscale flux range between 4.6 and 100 mJy beam$^{-1}$. The single-dish Bonn data has been folded into this image (f) Contours of SNR candidate G3.66-0.12 with levels at 1, 2, 3, 4, 6, 8, 10, 14, 18, 22, 30, 40, 50, and 60 mJy beam$^{-1}$. The beam size is 12.7$''$ × 8.5$''$ (PA=78$^0$) and a greyscale flux range between -1.7 and 10 mJy beam$^{-1}$.
Fig. 28.— (a) Contours at 1, 2, 3, 4, 5, 6, 7, 8, 10, 14, 18, 22, 30, 40, 50, 60 mJy beam$^{-1}$. The central structure G1.32+0.09 with an extent of 2$'$ $\times$ 4$'$ and a total integrated flux of 1.1 Jy. The beam size is 12.2$''$ $\times$ 8.2$''$ (PA=65$^0$) and a greyscale flux range between -4 and 20 mJy beam$^{-1}$. (b) Contours at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 11.8$''$ $\times$ 8.8$''$ (PA=82$^0$) and a greyscale flux range between -1 and 20 mJy beam$^{-1}$; (c) Contours at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 11.8$''$ $\times$ 8.8$''$ (PA=82$^0$) and a greyscale flux range between -1 and 20 mJy beam$^{-1}$; (d) Contours of HII region G4.57-0.12 with levels at 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$; (e) Contours of HII region G4.42+0.12 with levels at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$; (f) Contours of SNR candidate G4.27+0.04 with levels 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 11$''$ $\times$ 8.2$''$ (PA=88$^0$) and a greyscale flux range between -1.5 and 4 mJy beam$^{-1}$; (g) Contour levels at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 11$''$ $\times$ 8.2$''$ (PA=88$^0$) and a greyscale flux range between -1.5 and 4 mJy beam$^{-1}$; (h) Contour levels at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 12.7$''$ $\times$ 8.5$''$ (PA=77$^0$) and a greyscale flux range between -1.7 and 10 mJy beam$^{-1}$; (i) Contour levels at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 12.7$''$ $\times$ 8.5$''$ (PA=77$^0$) and a greyscale flux range between -1.7 and 10 mJy beam$^{-1}$; (j) Contours of an HII complex with levels at 1, 2, 3, 4, 6, 8, 10, 14, 18, 22, 30, 40, 50, and 60 mJy beam$^{-1}$. The beam size is 11.1$''$ $\times$ 8.4$''$ (PA=75$^0$) and a greyscale flux range between -0.5 and 2 mJy beam$^{-1}$; (k) Contour levels at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 11.1$''$ $\times$ 8.4$''$ (PA=75$^0$) and a greyscale flux range between -0.5 and 2 mJy beam$^{-1}$; (l) Contour levels at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 11.1$''$ $\times$ 8.4$''$ (PA=75$^0$) and a greyscale flux range between -1 and 5 mJy beam$^{-1}$; (m) Contour levels at 0.5, 1, 1.5, 2, 3, 4, 5, 7, 9, 11, 15, 20, 25, and 30 mJy beam$^{-1}$. The beam size is 11.8$''$ $\times$ 8.8$''$ (PA=82$^0$) and a greyscale flux range between -1 and 5 mJy beam$^{-1}$; (n) Contours of HII region G2.30+0.24 with levels at 1, 2, 3, 4, 6, 8, 10, 14, 18, 22, 30, 40, 50, and 60 mJy beam$^{-1}$. The beam size is 11.8$''$ $\times$ 8.8$''$ (PA=82$^0$) and a greyscale flux range between -1 and 20 mJy beam$^{-1}$.
Fig. 29.— The schematic diagram of all the identified radio filaments labeled in this survey. The position of Sgr A* is presented by a star. The light background circles show the angular size of the surveyed region. There is also a NRF G358.85+0.47 extending for 7′ in its length and runs along the Galactic plane (Lang et al. 1999). This NRF was not covered by our survey but is shown in this diagram.