Starburst Driven Thermal and Non-thermal Structures in the Galactic Center Region

F. Yusef-Zadeh(1), W. Cotton (2), J. Hewitt (1), C. Law (1), R. Maddalena (3) & D. A. Roberts (1,4)

(1) Dept. Physics and Astronomy, Northwestern University, Evanston, IL. 60208
(2) NRAO, 520 Edgemont Road, Charlottesville, VA 22903
(3) NRAO, PO Box 2, Green Bank, WV 24944
(4) Adler Planetarium & Astronomy Museum, 1300 S. Lake Shore Drive, Chicago, IL. 60605

Abstract.

We briefly review the prominent thermal and nonthermal sources near the Galactic center. These sources include the young stellar clusters, the Sgr B complex as well as the large-scale nonthermal filaments and lobes. Some of the recent radio images of this region based on VLA and Green Bank Telescope observations are also presented. We then argue that the origin of the large-scale features within the inner two degrees of the Galactic center is tied to a past starburst activity in the nucleus of the Galaxy.

1. Sgr A*, Young Stellar Clusters, Nonthermal Filaments and the Galactic Center Lobe

Like a jungle where many species evolve, share the same resources and interact with each other, the center of our Galaxy is occupied by an impressive collection of components that coexist and interact with each other. In this crowded environment, a clear understanding of the nature of these interacting components is not a trivial task. The difficulties within this environment such as crowding, a high visual extinction, as well as unusual physical conditions are responsible for much debate on the physical nature and origin of many objects in this complex region. However, when a clear picture is revealed, the impact of such a study can be significant as it provides much insight into the study of other regions and acts as a vehicle to explain the connection between the physical processes operating in the disk of the Galaxy and those within the nuclei of distant galaxies.

One of the components that has provided a great deal of excitement in recent years is the compact nonthermal source Sgr A* whose luminosity is thought to be due to accreting thermal winds from its neighboring cluster of massive stars. Sgr A* is considered to be a massive black hole at the dynamical center of the Galaxy. The revelation of a large concentration of dark matter $3-4 \times 10^6 \, M_\odot$ coincident with Sgr A* has created a much better picture of this object since its discovery 30 years ago (Schödel et al. 2003; Ghez et al. 2003). Presently, one of the key questions is whether the low luminosity of Sgr A* is due to the low accretion rate...
from mass-losing stars or the unusually high radiative deficiency of the accreting flow.

Another component that has attracted much attention recently is the discovery of several clusters of young, massive stars within the projected distance of 30 pc from the Galactic center. These objects are not run-of-the-mill clusters in the Galaxy and it is remarkable that at least three of such young and compact systems are found in a small volume of the Galaxy. These high density stellar systems, known as the Arches (G0.12+0.02), the Quintuplet (G0.15-0.05), and the central Sgr A clusters (e.g., IRS 16 and IRS 13), consist of mainly O and WR stars with individual stellar masses greater than 20 $M_\odot$. The Arches cluster contains more than 150 young, massive stars with emission lines, all of which are distributed within a few arcseconds of the core of the cluster (Figer et al. 1999). Recent theoretical studies of these types of massive clusters suggest that their short time scale for dynamical evolution can lead to the formation of intermediate mass black holes via runaway merging (McMillan et al. 2004). In fact, a recent claim suggests dynamical evidence for an intermediate mass black hole within the IRS 13 cluster near Sgr A* (Maillard et al. 2004).

These clusters provide an excellent laboratory to study both thermal and nonthermal processes. Multi-wavelength observations indicate ionized stellar winds arising from mass-losing WN and/or Of stars with mass-loss rates ranging between $10^{-5}$ to $10^{-4} M_\odot yr^{-1}$ (Lang et al. 2001a, b). Most of the observations in radio, X-rays, and near-IR wavelengths have concentrated on the study of thermal emission from ionized stellar winds in the cluster, however, WR+OB binary systems within these stellar clusters are also excellent sites for acceleration of particles to relativistic energies. Theoretically, at the contact discontinuity where the winds of a binary system collide with each other, particles are accelerated by first order Fermi acceleration in shocks which then results in significant radiation (Dougherty et al. 2003). The spectrum of radio emission from binary stars could vary between fully thermal and nonthermal and many isolated WR-OB binary systems have displayed this characteristic. Although free-free absorption in these sources can be important, the relativistic particles can leave the binary systems and the clusters to be injected into the ISM. Interestingly, nonthermal emission has recently been detected from the Arches cluster. This implies that this cluster consists of a number of colliding wind binaries (Yusef-Zadeh et al. 2003). The additional role of nonthermal particles can be the production of nonthermal $\gamma$-ray and X-ray emission from upscattering of the intense radiation field as well as the irradiation of adjacent molecular clouds. In fact, the Arches cluster is surrounded by the fluorescent 6.4 keV line emission and also displaced only by $\approx 200''$ from the nominal position of the unidentified EGRET source 3EG J1746–2851. The location and the spectrum of the $\gamma$-ray source is well within the 95% error radius of 0.13° and is consistent with inverse Compton scattering.

On a large scale, two other components that have been recognized for more than 20 years are the striking nonthermal filaments and the puzzling “Galactic Center Lobe”. The filaments are found only within the inner 2° of the Galactic center and have transverse dimensions that are roughly a fraction of a pc whereas their length is on the order of tens of parsecs. The Galactic Center Lobe consists of two “columns” of continuum emission with a degree scale (~150 pc) rising in
the direction away from the Galactic plane. Within the region where both the Lobe and the nonthermal filaments are found, there is considerable amount of thermal ionized and dust emission associated with star forming regions.

In order to get a better understanding of the Lobe and the filaments and their relationship to star forming regions, we recently carried out multi-configuration VLA and multi-wavelength GBT observations of several degrees of the Galactic center. We used the wide field imaging technique to correct non-coplanar effects at 1.4 GHz based on 40 overlapping VLA pointings. Figure 1 shows a segment of the survey image based on combining the VLA and GBT data at 1.4 GHz. Figure 2 shows a segment of GBT data displaying the Galactic Center Lobe at 5 GHz.

This study had led to several lines of evidence suggesting that the inner few hundred pcs of the Galaxy went through a burst of star forming activity less than 10 million years ago. One line of evidence comes from the number of young star clusters with similar ages of a few million years distributed in this region. The hallmark of an intense episode of star formation are the luminous, compact, young star clusters. Star cluster formation has also been considered an important mode of star formation in a high pressure environment in starburst galaxies. Numerical simulations of the evolution of massive star clusters within ~200 pc of the Galactic center predict that the inner 200 pc of the Galaxy could harbor some 10 to 50 young star clusters similar to the Arches and the Quintuplet clusters (Portegies Zwart et al. 2002). However, the high visual extinction and source confusion will make it difficult to unravel the hidden star clusters in this region (Law & Yusef-Zadeh 2004). An example in which star clusters may be hidden in a highly obscured region is the Sgr B complex. This complex consists of an evolved extended HII region Sgr B1 and the young Sgr B2 source whose emission is dominated by compact, bright continuum HII regions. Sgr B2 may signify the most spectacular on-going star forming region in the Galaxy containing more than 50 compact HII regions, many of which are excited by young massive stars. In the context of the starburst model in the Galactic center region, the Sgr B region is an example of a starburst that took place few million years ago. However, because of its dense and massive molecular environment, induced star formation has continued until present by expanding HII regions. Figure 3 shows a 1.4 GHz continuum image of the Sgr B2 complex.

Our 20cm survey has found a large fraction of the filaments showing jet-like morphology and a wide range of orientations with respect to the Galactic plane. Figure 4 shows a schematic diagram of the distribution of the filaments where more than 80 filaments are drawn. The longest filaments run roughly perpendicular to the Galactic plane whereas the short filaments do not show a preferred orientation. It is not a coincidence that the largest concentration of the filaments are populated in star forming regions and are found only within the inner two degrees of the Galactic center. These observations suggest the origin of the magnetic fields tracing the filaments is likely to be consistent with being local rather than global (LaRosa et al. 2004; Yusef-Zadeh 2003). Specifically, the filaments may be the result of nonthermal particles generated in the colliding winds of WR and OB stars. In addition, the same WR-OB binary systems can be responsible for much of dust formation found in the Lobe. Another speculation for the origin of the filaments is black holes, formed within massive
young clusters as a result of runaway merging, are responsible for launching narrow filaments.

Other independent studies of the ISM of the Galactic center region support a similar picture of starburst activity (Bland-Hawthorn & Cohen 2003; Rodriguez-Fernandez & Martin-Pintado 2004). In particular, recent ISO observations of ionized gas in this region show excitation and ionization parameters that are similar to some low-excitation starburst galaxies. We believe the unusual collection of remarkable thermal and nonthermal components found in the Galactic center region can be viewed as a manifestation of windy massive stars affecting their surrounding ISM in a starburst episode. In particular, a WR-type phenomenon may be a thread that connects the accreting material onto Sgr A*, young stellar clusters, the nonthermal filaments and the Galactic Center Lobe. Future study of this region can shed light on our understanding of more energetic a WR-type phenomena in distant galaxies and conversely, studying distant galaxies can aid our understanding of energetic WR-phenomena.

2. References

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Figure 1. A combined 20cm image from the VLA and GBT with a resolution of 30″. The features near the top are some of the nonthermal radio filaments. Some of the known supernova remnants (SNRs) and HII regions are also shown.

Figure 2. A 6cm image of the Galactic center region based on GBT observation with a resolution of 3′. The outline of the Galactic Center Lobe is drawn. The Galactic plane runs horizontally.

Figure 3. A 20cm image of the Sgr B complex region with a resolution of 2.5″×1.7″. Sgr B2 and Sgr B1 lie to the northeast and southwest, respectively. The Galactic plane runs diagonally.

Figure 4. A schematic diagram of all the identified radio filaments. The position of Sgr A* is presented by a star. The gray background circles show the extent of the surveyed region.
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