A Population of Compact Radio Sources at the Galactic Center

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Abstract. The radio bright zone (RBZ) at the Galactic center has been observed with the JVLA in the A, B and C array configurations at 5.5 and 9 GHz. With a procedure for high-dynamic range imaging developed on CASA, we constructed deep images at a resolution up to 0.2", achieving rms noises of a few $\mu$Jy/beam. From the high-resolution and high-dynamics range images at 5.5 and 9 GHz, a population of compact radio sources ranging from a few mJy to a few tens $\mu$Jy in flux density is revealed. The steep-spectrum radio sources in the RBZ are likely the candidates of high-energy objects that are associated with neutron stars and/or stellar mass black holes at the Galactic center. We report new results of the Cannonball and Galactic center transient (GCT).

1. High Dynamic Imaging

Utilizing the technique discussed in ZMG 2019, we constructed a high-dynamic image with the JVLA data observed at 5.5 GHz in A, B and C arrays, by adding old VLA D-array data as well as GBT single dish data. Fig. 1 shows the final image made with the hybrid data sets sampled in the UV domain from 0 to 800k$\lambda$, achieving rms 2 $\mu$Jy/beam or a dynamic range 360,000:1. We also imaged RBZ with only the large arrays’ data. For 5.5 GHz, the image made using the A array data with Briggs’ weight (R=0) while for the 9 GHz image, both A and B arrays’ data were used with R=0.5. Both images are convolved to a common beam 0.44"x0.20" (1.8 deg), with compatible rms of 3 $\mu$Jy/beam. The images are used to catalog the compact radio sources.

Cannonball was discovered in hard X-ray (Park et al 2005). The radio counterpart with a peak radio intensity of 500 $\mu$Jy/beam was detected with the VLA at both 5.5 and 8.3 GHz suggesting presence of pulsar wind nebula (PWN) with relatively flat spectra for the head and plume ($\alpha$=-0.44 and -0.1) and a steep spectrum tail ($\alpha$=-1.94) (ZMG2013). From two epochs’ data, the proper motion of $\mu_\alpha = 0.001 \pm 0.003$ asec/y and $\mu_\delta = 0.013 \pm 0.003$ asec/y was inferred, suggesting 500 km/s in transverse velocity. Adding two new epochs’ data, we derived a consistent result with better statistics: $\mu_\alpha = 0.0004 \pm 0.0025$ asec/y and $\mu_\delta = 0.0130 \pm 0.0027$ asec/y, suggesting $V_t = 483 \pm 94$ km/s. The age of 9300 y for Sgr A East SNR is inferred.

GCT was caught during its flare in 1990, reaching a peak in January 1991 with a flux density $\sim$0.9 Jy at 1.5 GHz greater than Sgr A*, and then subsequently declined at a rate of $\sim$22 mJy/day (Zhao et al. 1992). With the JVLA, we have detected significantly a compact object in radio the intensity of 61$\pm3$ $\mu$Jy/beam at 9 GHz in 2015 and 91$\pm10$
$\mu$Jy/beam at 5.5 GHz in 2014 at the position of the GCT. Assuming the GCT is in a quiescent state, no variations in flux density during 2014-2015 epochs, the spectral index of $\alpha = -0.81 \pm 0.25$ is inferred, consistent with $\alpha = -1.2$ during the 1990 flare.

![Image of RBZ at 5 GHz, with rms of 2 $\mu$Jy/beam and FWHM beam 0.68"x0.47" (8.4 deg).](image1.png)

![The Cannonball region.](image2.png)

![The GCT region, greyscale for 5.5 GHz and contours for 9 GHz; The rms noises are $\sim 3$ $\mu$Jy/beam, with FWHM beam of 0.44"x0.2" (1.8 deg).](image3.png)

![In addition to the GCT, a previous unknown source with a flat spectrum $\alpha = -0.14$ is also detected.](image4.png)

![Proper motion fit to RA offset of the Cannonball from Sgr A*](image5.png)

![Proper motion fit to Dec offset.](image6.png)

### 2. Summary

From our deep images of the RBZ at the Galactic center, at least a thousand of compact radio sources at a level of a few 100 $\mu$Jy in flux density at 5 GHz appear to hide in the overwhelming diffuse continuum emission from the region. High-resolution (0.2" images at 5.5 and 9 GHz have revealed the presence of a sub-group of high energy objects, among the population of compact radio sources, that are associated with non-thermal radiation. The characteristics in radio spectrum suggest that they are the candidates related to binary systems bounded with either neutron stars or stellar mass black holes.

### References

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