Abstract

We propose to make the first interferometric molecular line and 3mm continuum surveys of the central molecular zone (CMZ) in the Galactic center. There are numerous motivations for such a high-resolution survey study and its comparison to those at other wavelength bands. One is to identify and probe the interaction sites of nonthermal electron population interacting with molecular clouds in the CMZ. Second, to gain a better understanding of a population of high velocity dispersion compact molecular clouds. These puzzling clouds were discovered by Nobeyama observations with poor spatial resolution. Third, to identify a population of ultracompact HII regions with high emission measures at 3mm. This has important implications on recent massive star formation in the Galactic center. Lastly, to determine the fraction of the IRDC cores in their quiescent or in active phase using molecular line ratios.

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Total Hours: 90.1

Special Requirements

None

Status of Prior CARMA Observations

c0489 - Continuum map from that project is shown in Figure 2. This proposal is in part to expand the area covered by that map, and improve the portions that suffered poor weather.
Scientific Justification

The inner few hundred pc of the Galactic Center (GC) differs from the rest of the Galaxy in its ISM properties. The central molecular zone (CMZ) is occupied by an impressive collection of massive molecular clouds (Sgr B2, Sgr A-D) which are characterized by a rich chemistry, broad linewidths, elevated temperatures and high density compared to those in the disk of the Galaxy. Remarkably, these molecular clouds emit fluorescent Fe Kα line emission at 6.4 keV. This region is also characterized by strong nonthermal radio continuum flux associated with several supernova remnants (SNRs) and ~100 individual GC radio filaments implying a high cosmic ray ionization rate. A high resolution study of the GC clouds when compared with other high resolution maps at other wavelengths bands help bridge a gap in our understanding of radiation processes operating at low and high energies.

Numerous molecular line survey observations of the CMZ over the last 30 years have solely been carried out with single dish telescopes with moderate resolutions. The most comprehensive survey of the CMZ was carried out recently by MOPRA which fully mapped in 18 molecular lines emitting from the inner $2.5^0 \times 0.5^0 (l \times b)$ between 85 and 93 GHz [1]. Using the flexible capabilities of CARMA, we propose the first interferometric molecular line survey of the Galactic center. Our strategy is to image the inner 650 sq. arcmin of the Galactic nucleus ($-0.2^\circ < b < 0.1^\circ$, $-0.2^\circ \leq \ell \leq 0.4^\circ$) in four molecular lines including SiO and HCO$^+$ lines as well as in the 3mm continuum. The proposed study will provide a legacy for present and future comparison with similar resolution maps made with facilities such as Chandra, VLA, HST/NICMOS, ALMA, Planck, and SOFIA.

One of the key motivations for the proposed study is to examine the relationship between the distribution of the molecular line emission as probed in different wavelength bands and to examine the origin of activity in this region. The electron population from GC diffuse synchrotron emission interacting with molecular gas will have several signatures such as cosmic ray heating and ionization of molecular gas. In addition, 6.4 keV Kα line emission from neutral iron atom can be produced by a high low-energy cosmic ray bombardment of neutral gas [2,3,4]. A three-way spatial correlation between the distributions of molecular gas, nonthermal radio continuum as the source of cosmic rays and the 6.4 keV line emission will be made as probes of cosmic ray interactions[5]. The comparison of high resolution radio continuum (VLA), X-ray (Chandra) data ~ $2 - 10''$ with integrated HCN line intensity map taken with ~ $39''$ resolution MOPRA data are shown in Figure 1a,b. Present spectral line single-dish data have insufficient spatial resolution to make this comparison but we will establish the three-way spatial correlation.

Some of the signatures of the dynamical interaction between GC filaments and molecular clouds are spatial distortions at the edge of clouds, higher velocity dispersion, higher cosmic ray ionization rate, as traced by highly elevated gas temperatures and varying abundance of certain molecules. A higher abundance of SiO from a 2′ resolution map has shown a strong correlation between the line ratio SiO/CS and Kα line emission from GC clouds [6]. Also, the abundance of HCO$^+$ is predicted to decrease with increasing cosmic ray ionization rate [7]. Given the high cosmic ray ionization rate inferred from H3$^+$ line measurements [8,9], we will seek for such signatures in molecular clouds considered to be interacting with SNRs and nonthermal radio filaments (NRFs).

II. Nobeyama observations (NMA) have discovered a population of high velocity dispersion compact clouds HVCC in the CMZ [10,11]. The best studied example of this population of clouds
compact clouds is G0.02-0.02 exhibiting a 100 km s$^{-1}$ velocity width, with high density and temperature with n(H2)$\sim 10^4$ cm$^{-3}$ and T$_k \sim 60$K [10]. These authors suggest that these clouds have been accelerated, heated, and compressed in a series of supernova shocks that occurred within the last (3-5)$\times 10^4$ yr. Figure 1c shows the positions of these clouds as crosses superimposed on an HCN image of the CMZ. None of these pc-scale high velocity dispersion clouds have been investigated with interferometry with the exception of G0.02-0.02. The proposed high resolution measurements will investigate their structure, their high velocity dispersion and their compactness to further our understanding of these puzzling sources.

III. Figure 2 (left) shows a mosaic image of 20cm continuum emission from the CMZ [12] where prominent star forming sites and nonthermal sources are located (Sgr A–E and the radio arc) [13]. Although there is a high concentration of diffuse HII complexes distributed in the GC region, there is no high frequency continuum survey of this region, other than our current CARMA D-array map (Figure 2, right) which shows tantalizing number of compact sources near the noise limit. Previous continuum surveys of the GC have never explored this class of compact HII regions with emission measures ranging between $10^7$ and $10^9$ pc cm$^{-6}$. The proposed continuum measurements at 3mm will be able to identify a population of ultracompact HII regions and new sights of early star formation. These measurements can then be correlated with other tracers of young massive star formation such as H$_2$O, methanol masers and 24$\mu$m survey data, all of which are already in hand. In addition to the proposed CARMA-8 short-spacing data, we will apply to GBT/MUSTANG for continuum zero-spacings of CARMA-15 and use the MOPRA maps for zero-spacing spectral line.

IV. The physical characteristics of molecular gas in the CMZ are similar to those of infrared dark clouds (IRDCs) but with both cold and hot temperatures (T$\sim 40$ and 200K). What fraction of the IRDC cores in this region is in their quiescent or in active phase? The quiescent cores display no IR emission and are thought to be starless cores whereas active cores show excess 4$\mu$m emission due to shocked gas and coincide with 24$\mu$m sources [13]. We will use the molecular line ratios to separate active cores with a rich molecular line spectrum consistent with hot core chemistry from quiescent cores with cold dense gas. The proposed intensity ratio measurements of SiO and HCO$^+$ to CO can be used to distinguish between active and quiescent star formation.

Technical Justification The correlator bands will be 4x500 MHz/3BIT in continuum and 4x125 MHz/3BIT placed on the lines of HCO$^+$, HCN, SiO, and CS, giving 2.5 km/s resolution. A 650 sq. arcminute map requires 456 CARMA-15 fields on a full beamwidth hexagonal mosaic. By sampling on the full beamwidth of the 10m antennas rather than Nyquist sampling, we can cover much larger area, paying a modest price in image fidelity. As an example, Figure 2b is sampled this way, yet many features not previously seen at 3mm are clearly evident. Note also such a mosaic is roughly Nyquist sampled for the 6-m antennas. Once the large survey is complete, follow-up Nyquist-sampled observations of the most interesting features could be proposed. Based on MP’s experience with NGC1333 large mosaic, the 456 fields can be covered in a single track with 15-20 second integrations. Tracks on subsequent nights use different mosaic starting points and/or reverse the mosaic sequence to regularize the uv coverage. In D-array, 25 hours gives a continuum sensitivity of $\sim 3$ mJy and a line sensitivity of $\sim 200$ mJy/channel or about 0.5K in the synthesized beam. Shorter-spacing data will be acquired with CARMA-8 SL configuration, in which the same area can be covered by 279 Nyquist-sampled fields. For this array, 65 hours give a continuum sensitivity of $\sim 5$ mJy/beam.
Fig. 1.— Left: Contours of the equivalent width of FeI Kα line emission superimposed on a 20cm grayscale continuum image. Right: Similar to (a) except that the grayscale image shows a HCN map of the CMZ. Bottom: The positions of high velocity dispersion compact molecular clouds are superimposed on the integrated HCN line intensities of prominent molecular clouds in the CMZ.

Fig. 2.— Left: A 20cm continuum survey of the Galactic center with 30″ resolution [6]. The rectangle indicates the region we propose to survey with CARMA. Right: Our existing CARMA D-array 3mm continuum map (rms ~ 5 mJy/beam) showing many of the features in the 20cm map. For instance, the Radio Arc can be seen (8 mJy/beam). As part of this proposal, we will expand this map and improve the S/N, particularly at ℓ > 0.05, which had poor weather.