Physical conditions and chemistry of the gas in Sgr C

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Introduction

The Sgr C is a prominent molecular cloud complex located in the Central Molecular Zone (CMZ) of the Galactic Center (GC), about 90 pc from Sgr A*. Similar to other GC clouds, Sgr C exhibits high velocity dispersions and elevated gas temperatures compared to molecular clouds in the Galactic disk [1]. Recent multi-wavelength observations have revealed that Sgr C is a highly complex region shaped by magnetic fields, shocks, star formation, and energetic feedback. JWST observations showed filamentary ionized gas structures and ongoing star formation activity, including massive protostars and numerous molecular outflows [2, 3]. X-ray observations suggest the presence of a young embedded supernova remnant [4], and orbital models indicate that Sgr C follows a complex x2-type orbit within the Galactic bar potential [5]. Our work investigates the physical conditions and heating/chemistry of the molecular gas in Sgr C to improve our understanding of the region.

Observations and Methodology

Our study uses observations of the IRAM 30m, APEX, and XMM-Newton telescopes towards eight regions of Sgr C (see Fig. 1) exposed to UV radiation (positions 1U-4U), X-rays (positions 5X and 6X), and shocks (positions 7S and 8S). Gas temperatures ($T_{\rm kin}$) were derived from CH_3CCH emission, densities (n_{H_2}) were estimated with RADEX modeling [6] of CO lines, and HNCO and SiO were used to study shock chemistry, while X-ray luminosities (L_X) were calculated to assess the impact of X-rays.

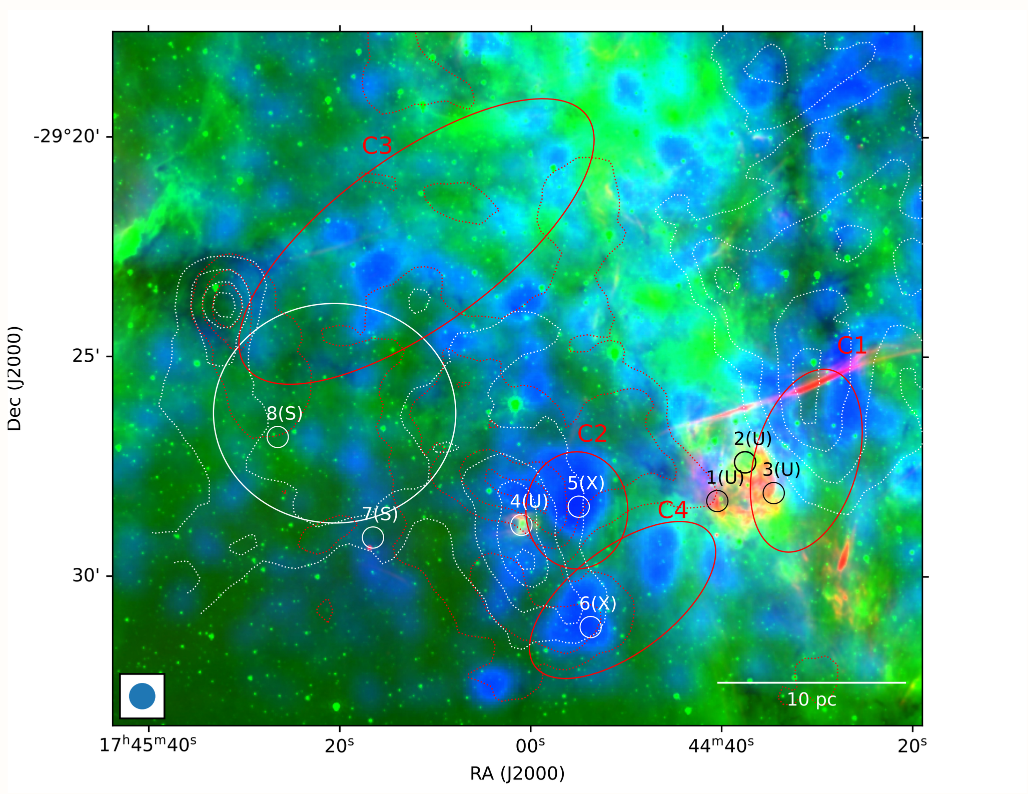

Figure 1: Sgr C region at multiple wavelengths: Spitzer 8 µm emission (green, [7]), XMM-Newton 6.4 keV Fe Kα emission (blue), and MeerKAT 20 cm radio emission (red, [8]). The eight observed positions are marked with circles corresponding to the IRAM 30m beam size of 28″. HCN J=1-0 emission from Mopra is overlaid as contours for two velocity ranges (-120 to -70 km s^{-1} in white and -70 to -10 km s^{-1} in red), together with several bright Fe Kα clumps (C1–C4). The big white circle highlights a molecular shell that would be created by cloud-cloud collisions [9].

Results

Expanding gas, shocks and $T_{\rm kin}$

Figure 2 shows the spectra of ^{13}CO, C^{18}O, HNCO, SiO and CH_3CCH, together with the LTE fits obtained with MADCUBA [10] to calculate excitation temperatures and column densities. Multiple velocity components are detected at positions 4U–8X, while positions 1U–3U show only a single gas component. The molecular lines in position 7S exhibit high velocities ($\sim$-112 km s^{-1}) and broad widths ($>$24 km s^{-1}), suggesting an expanding gas. Position 4U also shows a high-velocity gas ($\sim$-100 km s^{-1}) likely associated with the interaction between molecular gas and an H II region.

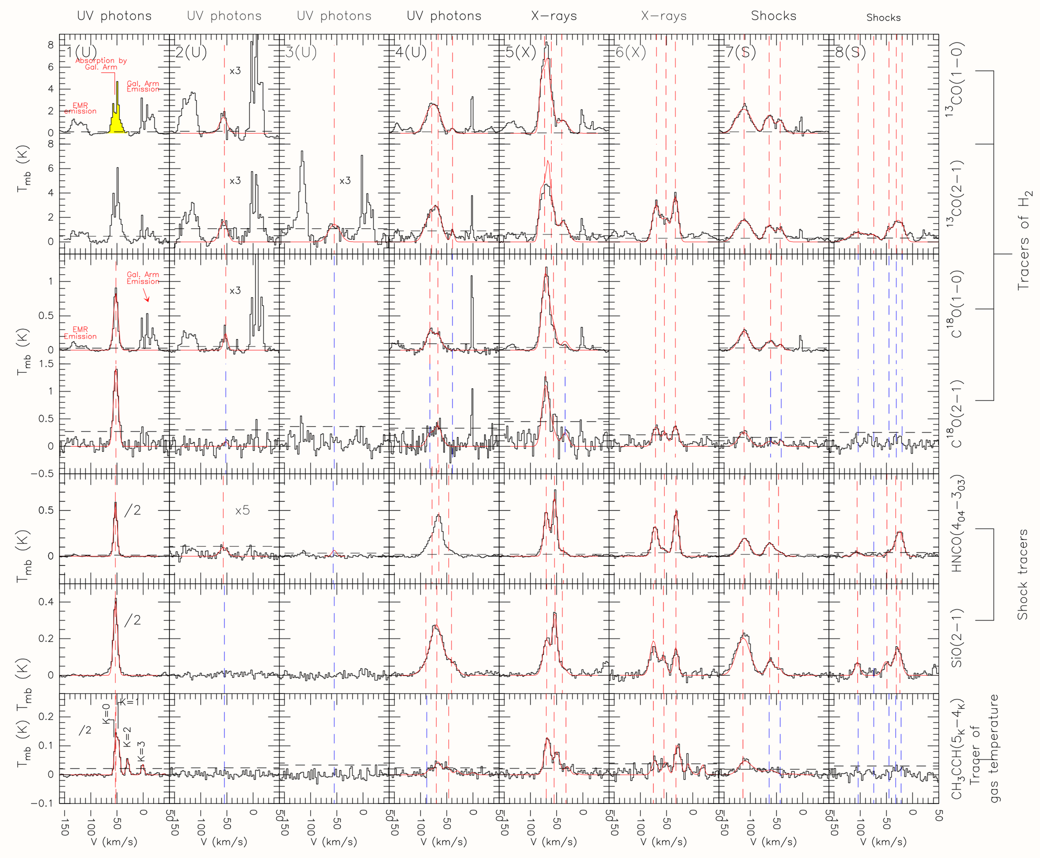

Figure 2: Spectra of several molecular line tracers observed towards eight positions in Sgr C, highlighting regions exposed to different heating mechanisms (UV photons, X-rays and shocks). Best-fit line profiles (in red) and velocity components derived with MADCUBA are shown, revealing multiple velocity structures in pos. 4U-8S (indicate with vertical dashed lines). Foreground absorption features, and emission associated with Galactic arms and the Expanding Molecular Ring (EMR) are also indicated. Horizontal dashed lines show 3σ.

LTE analysis of CH_3CCH lines (see line fitting in Fig. 2) revealed $T_{\rm kin}$ of ~40–80 K in Sgr C. Derived HNCO and SiO abundances relative to H_2 are consistent with UCLCHEM shock models [11] involving low-velocity (20 km s^{-1}) shocks in gas with densities of 10^3 cm^{-3} (calculated for Sgr C, see next section). To calculate the abundances, the H_2 column densities were inferred from those of C^{18}O assuming the ^{16}O/^{18}O ratio of 250 [12] and a relative abundance of CO to H_2. The modeled temperatures also agree with the observed values, suggesting that low-velocity shocks play an important role in the chemistry/heating of the molecular gas in Sgr C.

H_2 densities

For the RADEX modeling of the ^{13}CO and C^{18}O lines, we explored grids of n_{H_2}, $T_{\rm kin}$, and column densities, with line widths fixed from MADCUBA results and assuming a beam filling factor of unity.

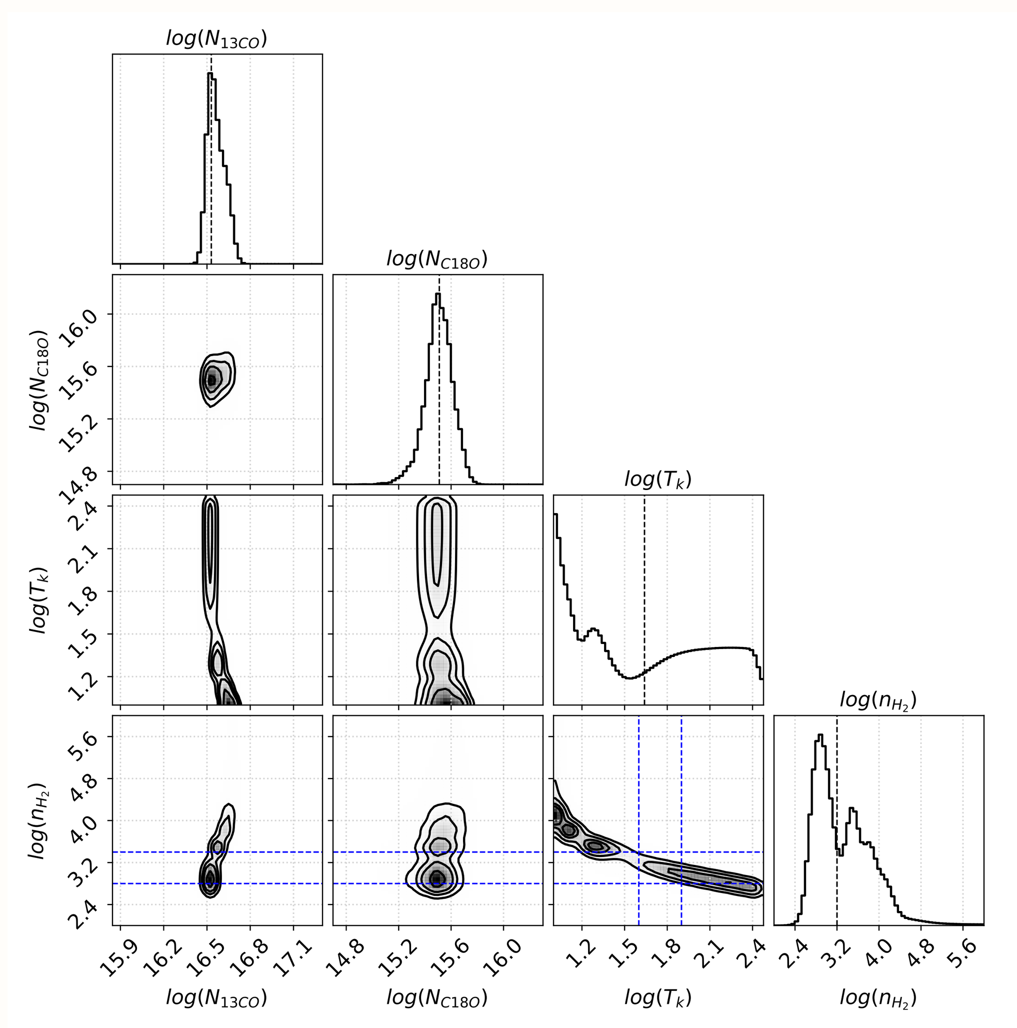

Figure 3: 1D and 2D likelihood distributions from the RADEX analysis for position 4U. Median parameter values are indicated with black dashed lines, while CH_3CCH-derived $T_{\rm kin}$ constraints (vertical blue dashed lines) are used to limit the range of acceptable n_{H_2}. The median values of $T_{\rm kin}$ and n_{H_2} differ from the peak likelihood values, whereas the column density medians closely match the distribution peaks.

A χ^2 analysis was performed to evaluate the goodness of fit of the RADEX models by comparing the integrated intensities modeled and observed of the ^{13}CO and C^{18}O transitions. The best-fit physical parameters were obtained from the minimum values of χ^2, while the probabilities for each parameter set were calculated assuming a multivariate Gaussian distribution (see Fig. 3). A mean value of $\log(n_{H_2})$ ~3.2 cm^{-3} is found for Sgr C.

X-rays in Sgr C

Using Xspec software [13], we also fitted the X-ray spectra of the eight positions (see the spectrum for position 5X in Fig. 4). Thus, 2-10 keV band L_X of 10$^{36.6}$-10$^{37.6}$ erg s^{-1} were derived, leading to estimates of X-ray ionization rates (ζ_X) of $\lesssim 5\times10^{-17}$ s^{-1} ($\zeta_X \approx 10^{-11}\frac{L_X}{10^{44}\,{\rm erg\,s^{-1}}}$, [14]), which is at least a factor of 20 lower than the known cosmic-ray ionization rates required to explain the temperatures through the CMZ [15].

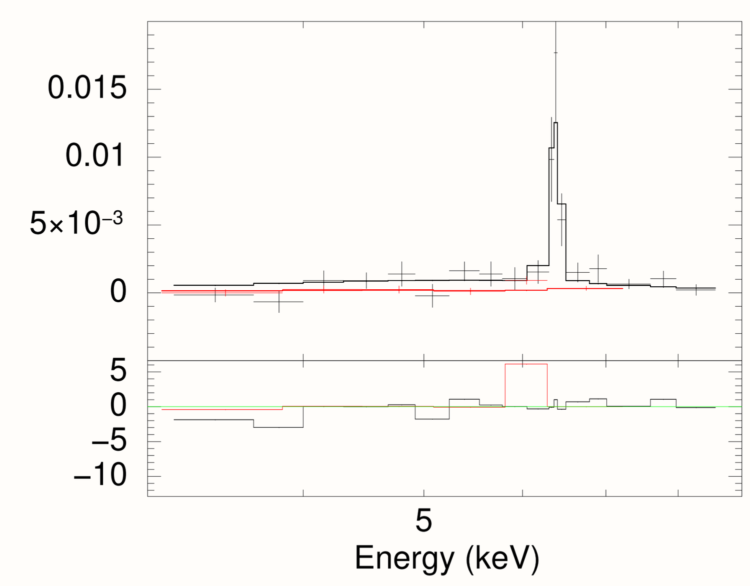

Figure 4: X-ray spectrum and best-fit model for position 5X in Sgr C. Y-axis is in units of counts s^{-1} keV^{-1}. The 6.4 keV Fe Kα line is detected. The bottom panel shows the residual.

Conclusions

- The high-velocity gas and broad linewidths are evidence of expanding gas in Sgr C regions.
- The abundances of HNCO and SiO are well explained simultaneously by chemical models that mimic low-velocity shocks of 20 km s^{-1}.
- By modeling ^{13}CO and C^{18}O lines with RADEX, we found a mean density of $\log(n_{H_2})$~3.2 cm^{-3} for Sgr C. Our LTE analysis of the CH_3CCH lines showed $T_{\rm kin}$ of ~40-80 K in Sgr C.
- We found low values of $\lesssim 5\times10^{-17}$ s^{-1} for the ζ_X, supporting that X-rays are not a dominant driver of gas chemistry/heating in Sgr C.

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