The Galactic Center: Feeding and Feedback in a Normal Galactic Nucleus
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The thermal state of molecular clouds in the Galactic center: evidence for non-photon-driven heating

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Abstract. We have used the Atacama Pathfinder Experiment (APEX) 12 m telescope at 218 GHz to observe molecular clouds simultaneously in the $J_{\mathrm{K_aK_c}} = 3_{03} \rightarrow 2_{02}$, $3_{22} \rightarrow 2_{21}$, and $3_{21} \rightarrow 2_{20}$ transitions of para-H_2CO to determine kinetic temperatures of the dense gas in the central molecular zone of the Galaxy. Gas kinetic temperatures for individual molecular clouds range from 55 to 125 K or even higher. The molecular clouds at high temperatures may be heated by turbulent dissipation and/or cosmic-rays.

Keywords. galaxy: center – interstellar medium: clouds – ISM: molecules – radio lines: ISM

1. Introduction

The Galactic center (GC) region is the most nearby galaxy core. It is characterized by a large concentration of molecular gas and by extreme conditions like high mass densities, large velocity dispersions, strong tidal forces, and strong magnetic fields. Therefore it is a unique laboratory to study molecular gas in an environment which is quite different from that of the Milky Way's disk. For a general understanding of the physics involved in galactic cores, measurements of basic physical parameters such as molecular gas density and gas kinetic temperature are indispensable.

2. Observations and results

Simultaneous measurements of the $J_{\mathrm{K_aK_c}} = 3_{03} \rightarrow 2_{02}$, $3_{22} \rightarrow 2_{21}$, and $3_{21} \rightarrow 2_{20}$ transitions of para-H_2CO were obtained with APEX at 218 GHz. The FWHM beam size was approximately $30''$. We used the On-The-Fly observing mode measuring $4' \times 4'$ maps, and the surveyed area is 302 square arcmin and its dimension is roughly $40' \times 8'$ along the Galactic plane. Figure 1 shows integrated intensity maps of the GC.

To investigate the gas excitation from the H_2CO line measurements, we use a one-component large velocity gradient (LVG) radiative transfer model and choose a spherical

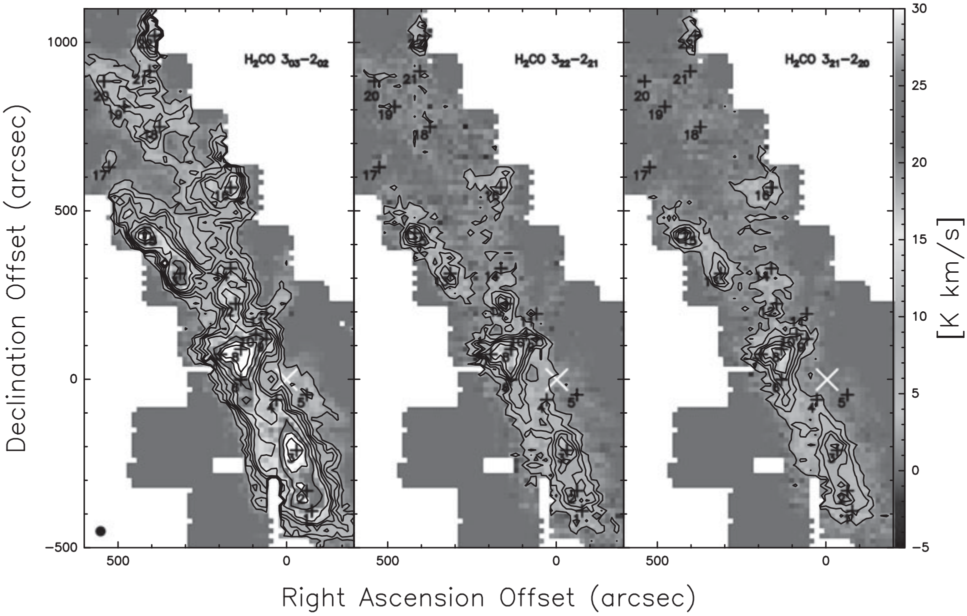

Figure 1. Integrated intensity maps for the different transitions of para-H_2CO, $J_{K_a K_c} = 3_{03} \rightarrow 2_{02}$ (**left**), $3_{22} \rightarrow 2_{21}$ (**middle**), and $3_{21} \rightarrow 2_{20}$ (**right**), observed in the GC. Black contour levels are for the molecular line emission, and the wedge at the side shows the intensity range of the line emission. The beam size is shown at the bottom-left corner of the left panel.

cloud geometry with uniform kinetic temperature and density. Gas temperatures range from 50 K to above 100 K. While a systematic trend of (decreasing) kinetic temperature versus (increasing) angular distance from the nucleus is not found, the clouds with highest temperature ($T_{\rm kin} > 100$ K) are all located near the center. A gas temperature of 65 ± 10 K is found for more diffuse molecular gas outside of the dense cores in the GC region.

3. Heating mechanisms in the GC clouds

What does heat the dense gas to high temperatures in the GC? The four most common mechanisms to heat the gas in molecular clouds are (a) photo-electric heating in photon-dominated regions, (b) X-ray heating, (c) cosmic-ray heating, and (d) turbulent heating.

Comparing the gas cooling rates and the heating rates from different mechanisms, we conclude that cosmic-ray heating and turbulent heating are good candidates to heat gas to high temperatures observed in the GC. However, we cannot distinguish which mechanism dominates the heating of molecular clouds in the GC. Future observations of $x(e) = \frac{n_e}{2n_{H_2}}$ (the average ionization fraction) can also help distinguish between these two heating mechanisms as high cosmic-ray energy densities will boost this fraction unlike turbulence (Papadopoulos 2010). With a large array such as ALMA, one can try to search for molecular clumps with thermal line widths, i.e. with line widths that are dominated by thermal motion. If such objects can be found, turbulent heating can be excluded because the narrow line widths cannot be explained by turbulent heating.

The high temperatures of molecular clouds over large scales in the GC region may be driven by turbulent energy dissipation and/or cosmic-rays instead of photons. Such a non-photon driven thermal state of the molecular gas provides an excellent template to study the initial conditions and star formation for the galaxy-sized gas in ultraluminous infrared galaxies.

Reference

Papadopoulos, P. P. 2010, *ApJ* 720, 226