The thermal state of molecular clouds in the Galactic center: evidence for non-photon-driven heating

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Background

The Galactic center (GC) region is the most nearby galaxy core. It is characterized by a large concentration of molecular gas located in the innermost few hundred parsec of the Milky Way 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.

The relative populations of the K_a ladders of H_2CO (see Figure 1) are almost exclusively determined by collisional processes. Therefore, line ratios involving different K_a ladders of one of the subspecies, either ortho- or para-H_2CO, are good tracers of the kinetic temperature. We therefore present observations of the H_2CO triplet at 218 GHz to study the gas kinetic temperatures of Galactic center clouds.

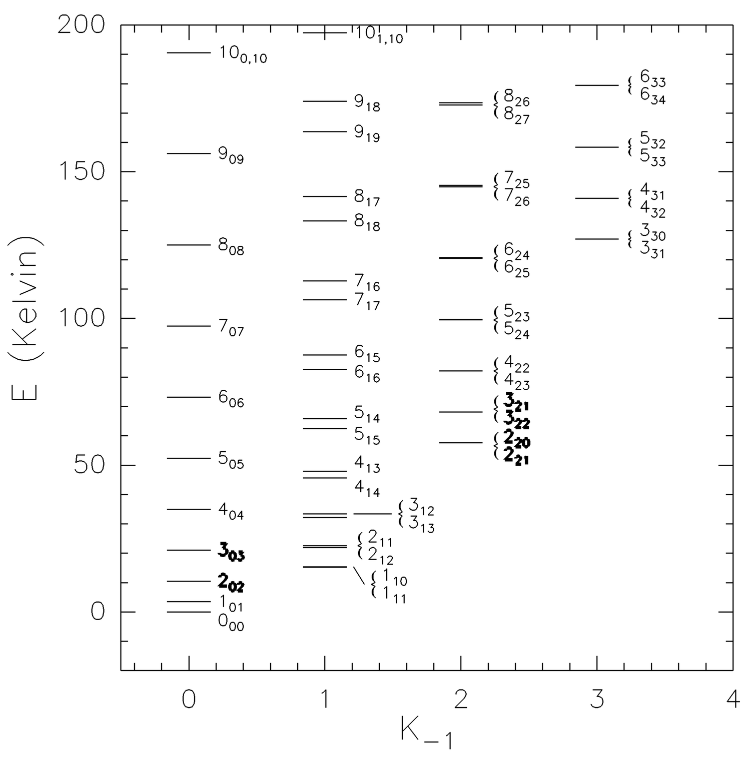

Figure 1 H_2CO energy-level diagram up to 200 K. The H_2CO 218 GHz transitions observed are shown in bold.

Observations and results

Simultaneous measurements of the $J_{K_aK_c} = 3_{03} \rightarrow 2_{02}$, $3_{22} \rightarrow 2_{21}$, and $3_{21} \rightarrow 2_{20}$ transitions of para-H_2CO (Figure 1) were obtained with APEX between 2010 April and 2010 June. 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 2 presents some characteristic spectra of the para-H_2CO triple, and Figure 3 shows integrated intensity maps in the GC.

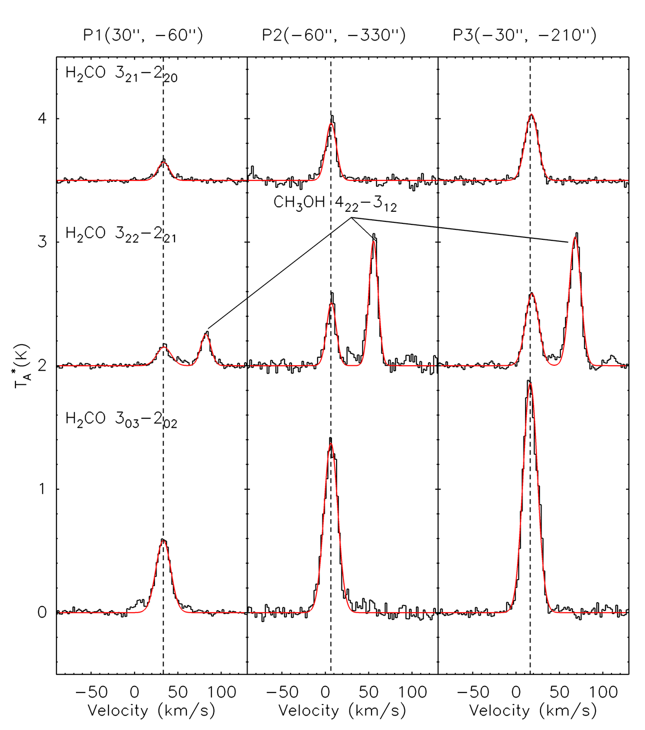

Figure 2 Spectra of the para-H_2CO triple. Gaussian fits are indicated by red lines.

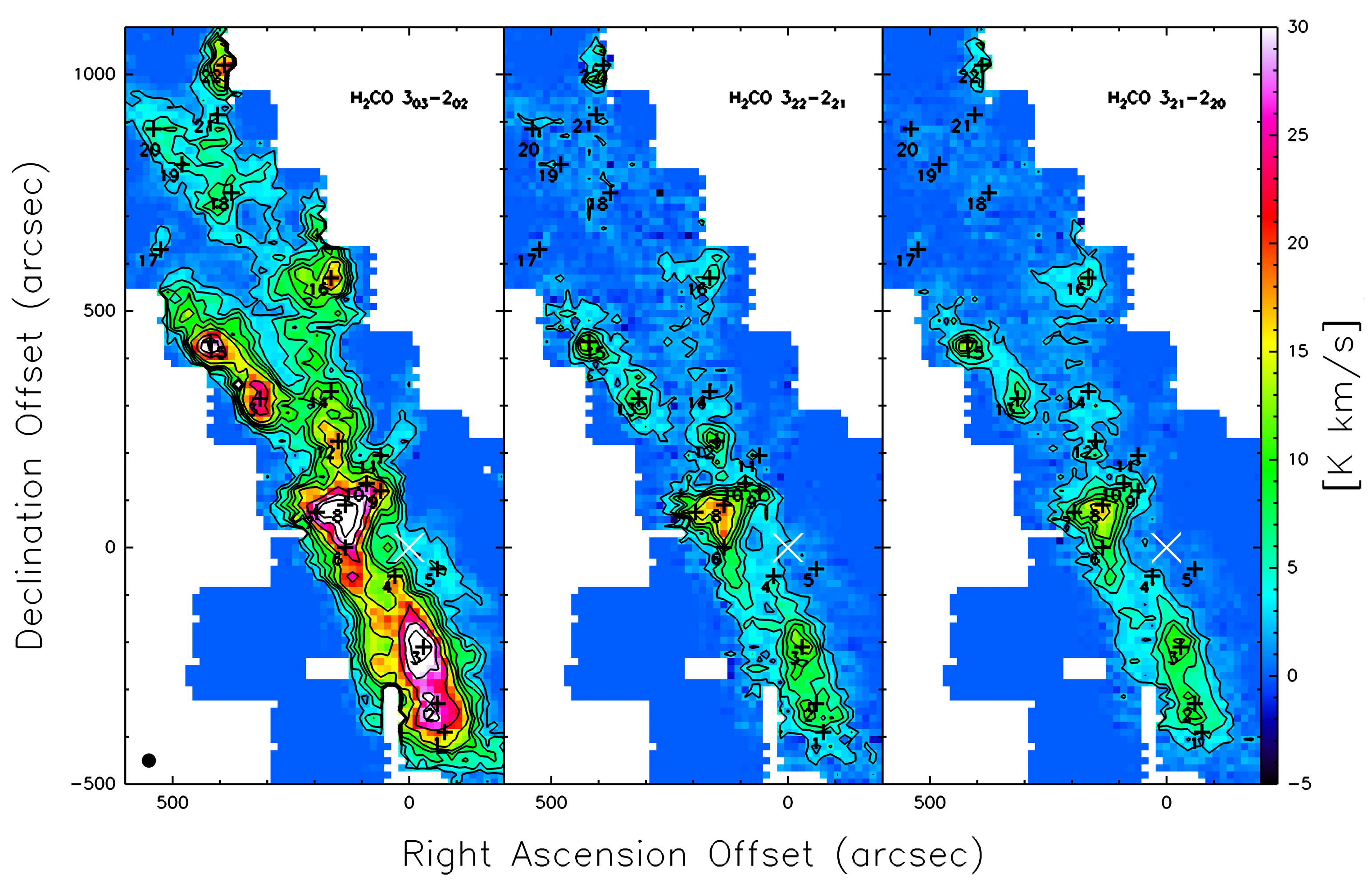

Figure 3 Integrated intensity maps for the different transitions of para-H_2CO, $J_{K_aK_c} = 3_{03} \rightarrow 2_{02}$ **(left)**, $3_{22} \rightarrow 2_{21}$ **(middle)**, and $3_{21} \rightarrow 2_{20}$ **(right)**, observed in the GC. Black contour levels are for the molecular line emission, and 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.

Kinetic temperatures of the GC clouds

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 cloud geometry with uniform kinetic temperature and density. Figure 4 shows an example of LVG modelling with the measured lines.

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 ($T_{kin} > 100$ 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.

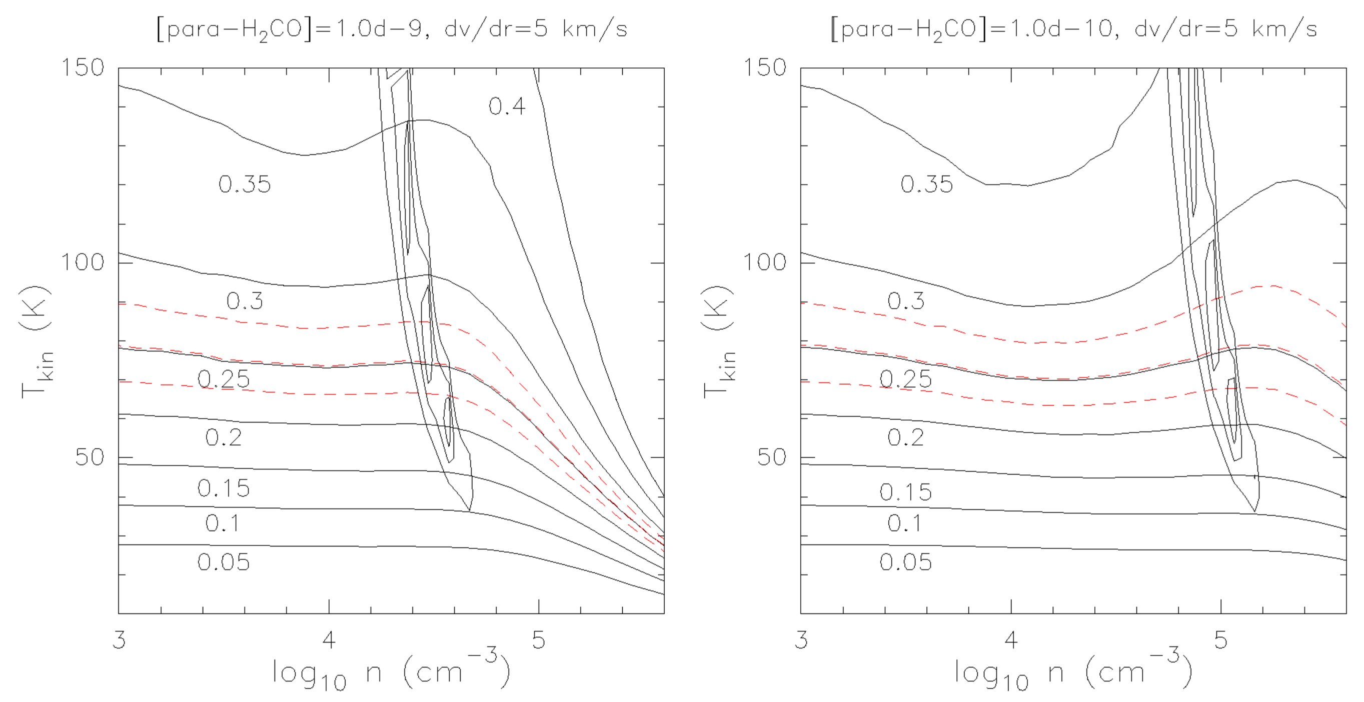

Figure 4 An example of LVG modelling. Reduced χ^2 distribution (mainly vertical contours) for a single component LVG model fit to the H_2CO brightness temperatures (black contours, χ^2 = 1,2,4) as well as H_2CO $3_{22} \rightarrow 2_{21}/3_{03} \rightarrow 2_{02}$ line ratios (mainly horizonal contours) as a function of n_{H_2} and T_{kin}. The diagram shows that for a given line ratio, the dependence on n_{H_2} is negligible at $T_{kin} < 100$ K in the case of optically thin H_2CO emission. On the other hand, the gas density is not well constrained because it is highly dependent on the adopted fractional abundance, velocity gradient and filling factors.

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 (PDRs), (b) X-ray heating (XDRs), (c) cosmic-ray heating (CRDRs), 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 the high temperature observed in the GC**. However, we cannot distinguish which of the two 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 help distinguish between these two heating mechanisms as high cosmic-ray energy densities will boost this fraction unlike turbulence.

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 intial conditions and star formation for the galaxy-sized gas in ultraluminous infrared galaxies.

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