^{13}CO (6–5) IN THE ORION BAR: A CRITICAL OBSERVATIONAL TEST FOR PDR MODELS

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1. Introduction

The Orion Bar is a limb–brightened edge of the cavity carved out in the Orion molecular cloud by the expanding HII region surrounding the Trapezium cluster. The Bar is one of the best studied Photon–Dominated Regions (PDRs; see Genzel in this volume for a review). Tauber et al. (1995) found a tight correlation between the distributions of the neutral atomic carbon and ^{13}CO (2–1) emission toward the Bar, which is difficult to explain in terms of classical PDR models. A possible explanation for this correlation was given by the geometric model of Hogerheijde et al. (1995) in which the PDR geometry changes from face–on to edge–on and back with increasing distance from the ionizing stars. The observed maximum of the molecular emission toward the Bar thus corresponds to a molecular column density peak and there are no significant variations in the excitation conditions across the Bar. In the present paper we investigate the uniformity of the excitation conditions across the Bar through observations of the ^{13}CO (6–5) and ^{12}CO (6–5) emission. We argue that the ^{13}CO (6–5) emission provides a critical test for models of this region and PDRs in general.

2. Discussion

The ^{13}CO (6–5) and ^{12}CO (6–5) emission toward the Orion Bar was observed in 1995 January using the Caltech Submillimeter Observatory on Mauna Kea, Hawaii. The FWHM beam size was $\sim 11''$. All temperatures reported here have been corrected for an efficiency of 60%, intermediate between the main beam efficiency ($\sim 45\%$) and the Moon efficiency ($\sim 70\%$). The (6–5) transitions were supplemented with maps of the (2–1) and (3–2)

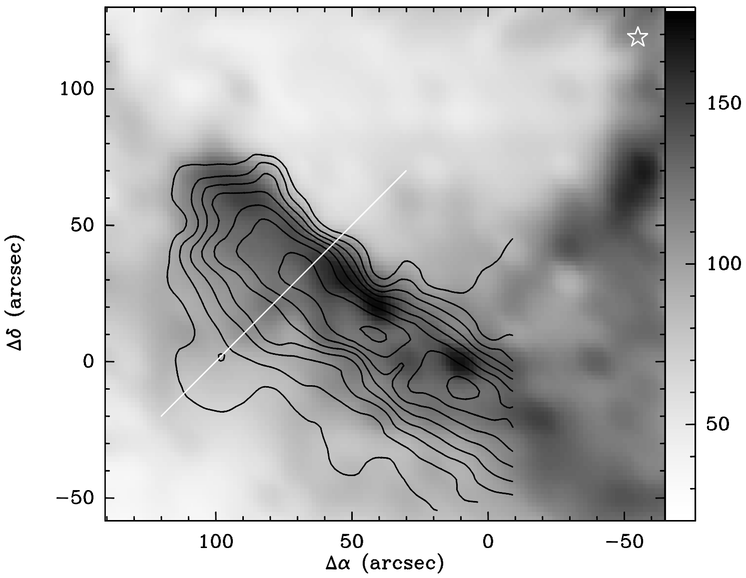

Figure 1. Overlay of the ^{12}CO (6–5) brightness temperature (gray–scale) toward the Orion Bar and the ^{13}CO (6–5) integrated intensity in the 5–15 km s^{-1} velocity range (contours). Contour levels are 40 to 180 in intervals of 20 K km s^{-1}. The star marks the location of θ^1C Ori.

transitions of the two isotopomers. We also observed one position toward the Bar in C^{18}O (6–5).

An overlay of the ^{13}CO (6–5) integrated intensity in the 5–15 km s^{-1} velocity range and the ^{12}CO (6–5) brightness temperature is shown in Figure 1. The peak ^{12}CO (6–5) brightness temperature toward the Bar ($\sim$ 175 K) is much higher than that observed in low–J ^{12}CO transitions in a similar beam ($\sim$ 120 K). This suggests that the ^{12}CO (6–5) transition becomes optically thick in outer PDR layers with higher kinetic temperatures. The ^{12}CO (6–5) emission is displaced toward the ionizing stars, relative to the ^{13}CO (6–5) emission. The peak brightness temperature of the ^{13}CO (6–5) emission is $\sim$ 75 K; such high intensities of the ^{13}CO (6–5) emission appear common in Galactic star–forming regions (Graf et al. 1993).

We computed preliminary PDR models for the Bar, assumed to be nearly edge–on, and the face–on "Hole" near the N–W end of the cut shown as the white line in Figure 1, using an improved version of the code of Le Bourlot et al. (1993). Our models can reproduce the observed intensities toward the Bar and the Hole for all CO transitions we observed *with the exception of* ^{13}CO (6–5). The intensities of ^{13}CO (6–5) are underestimated by factors of 2 and 3.5 toward the Hole and the Bar, respectively. The models fail because they predict a kinetic temperature of only $\sim 30 - 50$ K for most of the ^{13}CO emitting gas, while we derive a lower limit of 120 K from

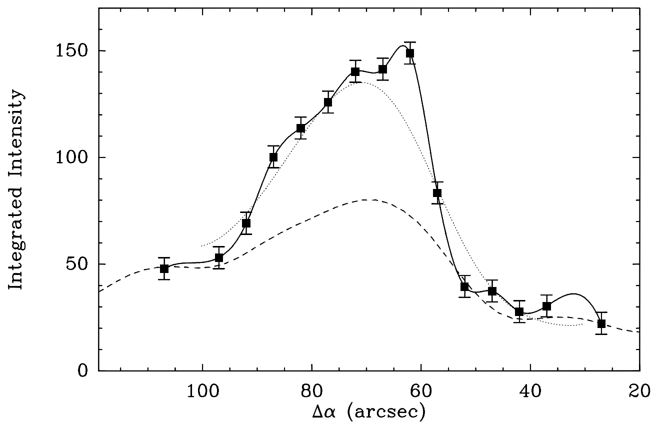

Figure 2. The variation of the ^{13}CO (6–5) and ^{13}CO (2–1) integrated intensity along the cut perpendicular to the Bar shown in Fig.1 (solid and dashed lines, respectively). Notice the very sharp drop of the ^{13}CO (6–5) emission on the side facing the ionizing stars. The ^{13}CO (2–1) intensities (from Tauber et al. 1995) were multiplied by a factor of 1.5. The distribution of ^{13}CO (6–5) integrated intensity calculated from an image convolved to the 30″ resolution of the ^{13}CO (2–1) map is shown as dotted line.

the observed ^{13}CO (6–5) to (2–1) intensity ratio.

The variation of the ^{13}CO (6–5) and (2–1) integrated intensities across the Bar is shown in Figure 2. The intensity ratio increases from ~ 1.5 toward the Hole to ≥ 2.5 toward the Bar. Since the ^{13}CO emission is at most only moderately optically thick ($\tau \leq 1$, based on the observed ^{13}CO to C^{18}O intensity ratio), this suggests a *significant difference* in the excitation conditions (kinetic temperature, density, or a combination of both) between the two regions.

We conclude that additional heating mechanisms for the interior (like shocks or turbulence) or time–dependent PDR models (e.g., Goldshmidt & Sternberg 1995) may be required to explain the high column density of *warm* ^{13}CO in the Orion Bar implied by our observations. We believe that this conclusion is true for PDRs in general and that observations of the ^{13}CO (6–5) emission provide a critical test for PDR models.

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