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A search for small-scale clumpiness in Orion and W3 high-mass star-forming regions

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Observations of distinct positions in Orion and W3 revealed ripples on the HCN(1–0), HCO^+(1–0) and CO(1–0) line profiles which can be a result of emission of a large number of unresolved thermal clumps in the beam that move with random velocities. The total number of such clumps is $\sim (0.4-4) \cdot 10^5$ for areas with linear sizes $\sim$0.1–0.5 pc.

Keywords: Interstellar clouds; Molecules

1 Introduction

There are many evidences that dense molecular cloud cores, where high-mass stars and stellar clusters are born, are clumpy on different spatial scales down to the scales unresolved by telescope beams. In particular, this follows from nearly constant volume densities in clouds with strong column density variations [1] or from detection of C I emission over large areas correlated with molecular maps [2]. An important evidence for small-scale clumpiness in high-mass star-forming (HMSF) regions is provided by observations of low relative intensity of the $F = 1-1$ HCN(1–0) hyperfine component compared to the optically thin case, which is connected with overlaps of thermal profiles of hyperfine components in higher HCN transitions. This phenomenon together with the fact that the observed line widths are highly suprathermal can be explained in the model with randomly moving thermal unresolved clumps [3].

Crude estimates for physical parameters of unresolved clumps can be obtained from simple analytical model [4, 5]. Assuming that clumps are identical with a small volume filling factor while velocity dispersion of their relative motions (σ) is much higher than inner velocity dispersion (v_0), we should expect an appearance of ripples in line profiles due to fluctuations in the number of clumps on the line of sight at various velocities. An extent of such ripples could be determined by the standard deviation for radiation temperature fluctuations in some range near the line center

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($\Delta T_{\rm R}$). In particular, total number of clumps in the telescope beam ($N_{\rm tot}$) can be derived from the following expression [5]:

$$\frac{\Delta T_{\rm R}}{T_{\rm R}} = \frac{\tau}{(e^{\tau}-1)\sqrt{N_{\rm tot}\frac{v_0}{\sigma}}},$$

where τ is line optical depth, that can be obtained from width comparison of the optically thick and thin Gaussian lines. Using the observed values of $\Delta T_{\rm R}$, peak line intensities ($T_{\rm R}$) and τ for two lines with different optical depths and knowing kinetic temperature it is possible to estimate the number of thermal clumps in the telescope beam.

Previously we used this approach in the analysis of the CS(2–1) and HCN(1–0) and their rare isotopes line profiles observed towards dense cores associated with S140, S199 and S235 HMSF regions [6]. The total number of clumps in the beam have been derived. Besides, clump densities, sizes and volume filling factors have been obtained from detailed model calculations. Here we present preliminary results of the line profile analysis towards selected positions in Orion and W3.

2 Small-scale clumpiness in Orion and W3

It is known that inhomogeneous clumpy structure is a feature of photon-dominated regions (PDR) that are usually located on the periphery of molecular clouds. One of the most well-known objects of that class is Orion Bar region. The HCN(1–0) spectra observed in this region show anomalies typical for massive dense cores [7]. Thus, one could also expect an existence of unresolved thermal clumps in this region.

In order to search and compare parameters of small-scale clumpy structure in dense core and PDR we selected position of maximum HCN(1–0) intensity in the Orion Bar region. For comparison the Orion KL position has been taken. Also, we selected two positions in W3 HMSF complex. The central part of this complex is known to have a rarefied structure, similar to clumpy PDR [8]. We selected position of maximum HCN(1–0) intensity near W3 IRS5 and W3(OH).

Long-time integration in the HCN(1–0) and HCO^+(1–0) lines that trace of high density gas ($\sim 10^5$–10^6 cm^{-3}) have been done at 20-m radiotelescope of Onsala Space Observatory. Rare isotopic lines, $H^{13}CN$(1–0) and $H^{13}CO^+$(1–0), have been used to determine optical depth of main lines. In order to determine parameters of lower density gas ($\sim 10^3 - 10^4$ cm^{-3}) that can trace interclump gas, the same positions have been observed in the CO(1–0) line at the 13.7-m telescope of Purple Mountain Observatory.

The list of the sources with coordinates, distances and linear resolutions at the frequencies of observations are given in Table 1. Integration times for the HCN, HCO^+ and CO lines vary from 2 hours to 11 hours.

The observed line profiles towards Orion KL and Orion Bar are given in Fig. 1. Below each profile residual fluctuations obtained after FFT filtering of the main profile component are given. The rejection level is equal to 0.8 (km/s)$^{-1}$ (see [6] for detailed description of this method).

Both for PDR and dense core positions in Orion dispersions of residuals within the line range for the HCN, HCO^+ and CO lines are significantly higher than dispersion

Table 1 Source list.

Source	α(2000) (^{h}) (^{m}) (^{s})	δ(2000) (^{o}) ($'$) ($''$)	D (kpc)	Resolution (pc)
Orion KL	05 35 14.5	–05 22 27	0.45	0.09–0.11
Orion Bar	05 35 20.1	–05 26 07	0.45	0.09–0.11
W3 IRS5	02 25 40.7	62 05 52	2.3	0.45–0.56
W3 (OH)	02 27 04.7	61 52 26	2.3	0.45–0.56

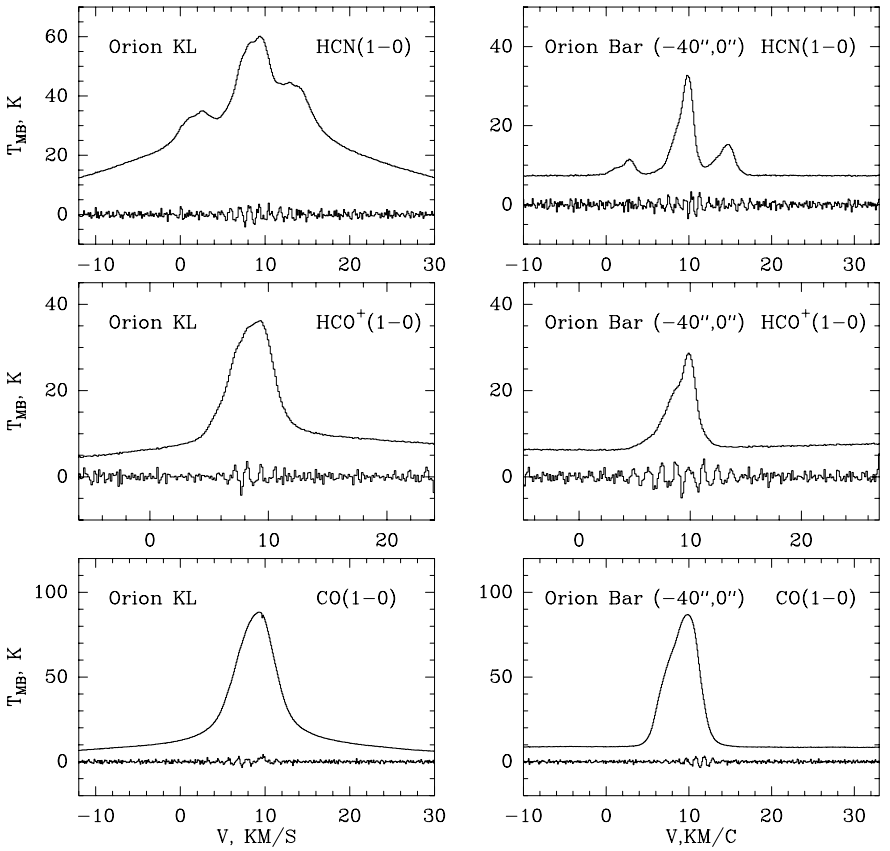


Figure 1 The observed line profiles towards Orion KL and Orion Bar (left and right panels, respectively). Residual fluctuations multiplied by a factor of ten are shown below each profile.

of noise. We also detected significant residuals for the HCO^+ line in W3 IRS5 and for the CO line in W3(OH). Unfortunatelly, the widths of Gaussian HCN and HCO^+ profiles in Orion Bar and of Gaussian HCO^+ profile in Orion KL are close to those of rare isotopes preventing to derive optical depth and total number of clumps. Yet, the $H^{13}CN$ profile towards Orion KL (ridge component) consist of two triplets we fitted

it with the single one to compare with results of HCN fitting. Therefore, one should treat the results for Orion KL with caution.

Peak line intensities, standard deviations of residual fluctuations within line range, and optical depths are given in Table 2 for Orion KL, W3 IRS5 and W3(OH). The total number of clumps in the beam is given in the last column. For W3(OH) we calculated τ and $N_{\rm tot}$ using CO and $C^{18}O$ [9] data. The subsequent data analysis will include detailed model calculations which should help to derive physical parameters of clumps.

Table 2 Line parameters and total number of clumps in the beam.

Source	Line	$T_{\rm R}(K)$	$\Delta T_{\rm R}(K)$	τ	$N_{\rm tot}$
Orion KL (ridge)	HCN(1–0)	~ 31	0.21	~ 1.5	~ 40000
W3 IRS5	HCO^+(1–0)	~ 15	0.04	~ 1.2	~ 400000
W3(OH)	CO(1–0)	~ 25	0.08	~ 2.6	~ 90000

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