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# The density structure of molecular cloud scales: A fitting for N-PDF with multi log-normal functions

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**Abstract.** We studied the probability distribution function of the column density (N-PDF) of molecular clouds based on a fit with a multi-log-normal function using the Nobeyama 45-m Cygnus X CO survey data. We identified 124 molecular clouds in $^{13}$CO data using the DENDROGRAM and SCIMES algorithms. The N-PDF was constructed for 11 extended ($\geq 0.4$ deg$^2$) molecular clouds of these identified clouds. We found that every N-PDF is well-fitted with one or two log-normal (LN) distributions. We investigated the distributions of the column density, C$^{18}$O dense cores, and radio continuum source in each cloud and found that the N-PDF was less correlated with the star-forming activity. The LN N-PDF parameters showed two impressive features. First, the LN distribution at the low-density part had the same mean column density ($\sim 10^{21.5}$ cm$^{-2}$) for almost all the molecular clouds. Second, the wider LN distribution tended to show the lower mean density of the structures.

**Keywords.** ISM: clouds – ISM: structure – ISM: molecules – methods: analytical – stars: formation

## 1. Introduction

The PDF of volume density ($\rho$-PDF) has been used as a powerful tool for investigating the density structure of molecular clouds affected by various physical processes (e.g. Vázquez-Semadeni 1994; Ballesteros-Paredes *et al.* 2011). It is determined by the dominant physical processes governing the density structure of molecular clouds; for

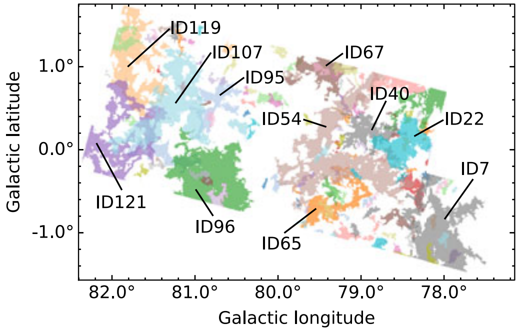


**Figure 1.** $^{13}$CO emission segmentation performed using DENDROGRAM and SCIMES algorithms. Each color shows an individual identified cloud. ID indicates clouds with an extract projected area over $\sim 4000$ pixels.

example turbulence and self-gravity should give the LN and power-law (PL), respectively. However, it isn't easy to obtain the $\rho$-PDF based on observations owing to the projection effect. Therefore, the N-PDF has mainly been used in observational studies.

Previous studies have shown that N-PDFs of many quiescent clouds are LN, whereas those of active star-forming clouds consist of two components: an LN and a pronounced PL tail in the high-density range. However, careful consideration is required for what functional form to fit the excess components in the high-density range. In some N-PDF studies, single or multiple power laws are applied even though the excess components of the high-density region are continuously curved on the log-log plane. Therefore, we investigated the N-PDF of molecular clouds based on a fit with a multi-LN function.

## 2. Data & Analysis

We used $^{12}$CO ($J = 1$–$0$) and $^{13}$CO ($J = 1$–$0$) line data from the Nobeyama 45-m Cygnus X CO Survey (Yamagishi *et al.* 2018). The effective angular resolution of the data cubes was 46″, which corresponded to 0.31 pc at a distance of 1.4 kpc to Cygnus X complex. The velocity resolution was 0.25 km s$^{-1}$. The typical noise levels of $^{12}$CO and $^{13}$CO data were 0.88 K and 0.36 K in $T_{\rm mb}$ scale, respectively.

We decomposed the intensity map into individual molecular clouds from $^{13}$CO data cube using DENDROGRAM and SCIMES algorithms. Figure 1 indicates the resultant molecular clouds. We set the dendrogram parameters, `min_value` $= 3\sigma$, `min_delta` $= 2\sigma$ and `min_npix` $= 64$, where $\sigma$ is the RMS noise level of the $^{13}$CO data.

The column density of $^{13}$CO is calculated assuming that the molecular clouds are under local thermodynamic equilibrium (LTE) with $^{12}$CO and the beam filling factors of both lines are unity. For the [$H_2$/$^{13}$CO] abundance, we applied a value of $7.7 \times 10^5$ (Wilson & Rood 1994; Pineda *et al.* 2010). To obtain an accurate N-PDF, we chose 11 clouds with an extracted projected area of over $\sim 4000$ pixels, i.e., 0.4 deg$^2$.

## 3. Results & Discussion

We found that some of the N-PDFs of 11 clouds have excess from a single LN distribution. These excess components of the N-PDFs showed a curve on the log-log plane. Thus, we fitted the N-PDFs with two LN distributions. The residuals after one or two LN components of the obtained N-PDFs showed no significant deviations in all column density ranges. Low-density and high-density LN distributions were referred to as LN1 and LN2, respectively.

We investigated the relationship between the number of LN distributions and star-forming activity by comparing the column density and spatial distributions of C$^{18}$O

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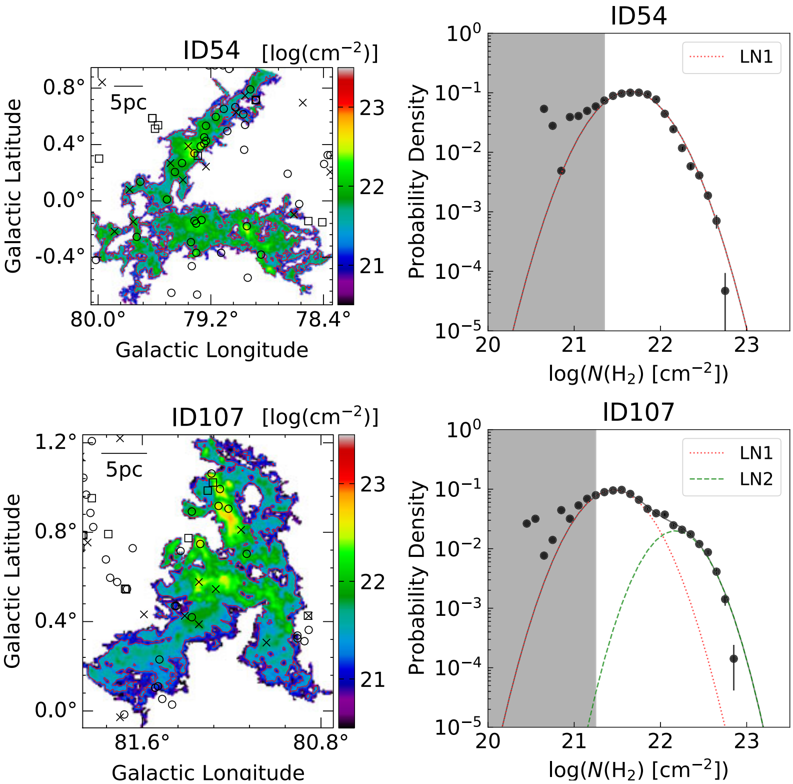


**Figure 2.** $H_2$ column density maps and their N-PDFs of typical clouds with a single LN (ID54) and double LN (ID107). The red contour indicates the completeness limit. The circles and crosses indicate the positions of the prestellar and starless cores identified by Takekoshi *et al.* (2019), respectively. The square symbol shows the center positions of the compact HII regions obtained by Urquhart *et al.* (2009).

cores and compact HII regions in each cloud (Figure 2). Consequently, we found no simple correlation between the number of $C^{18}O$ cores associated with molecular clouds and the N-PDF. Furthermore, the positional correlation between the compact HII regions and the high-density regions that compose LN2 ($\sim 10^{22.5}$ cm$^{-2}$) is also poor. Therefore, we considered there is little relationship between the star formation activity and N-PDF.

We performed a statistical investigation of the N-PDF using the fitting parameters of the N-PDF. In this study, we focused on the correlation between the surface fraction and width of the LN distribution with the mean column density. Panels (c) and (d) of Figure 3 indicates the correlation plots of the N-PDF parameters. We found two impressive features. First, the LN distribution at the low-density part had the same mean column density ($\sim 10^{21.5}$ cm$^{-2}$) for almost all the molecular clouds. Second, the width of the LN distribution tended to decrease with an increasing mean density of the structures. The two correlations suggest that a higher-density component has a smaller volume fraction and weaker turbulence within each structure.

It is unclear why the density structures of molecular clouds can be fitted only by two LN distributions. Observational studies with higher spatial resolution using various ISM probes and numerical simulations of the multi-phase ISM at later evolutionary stages are required.

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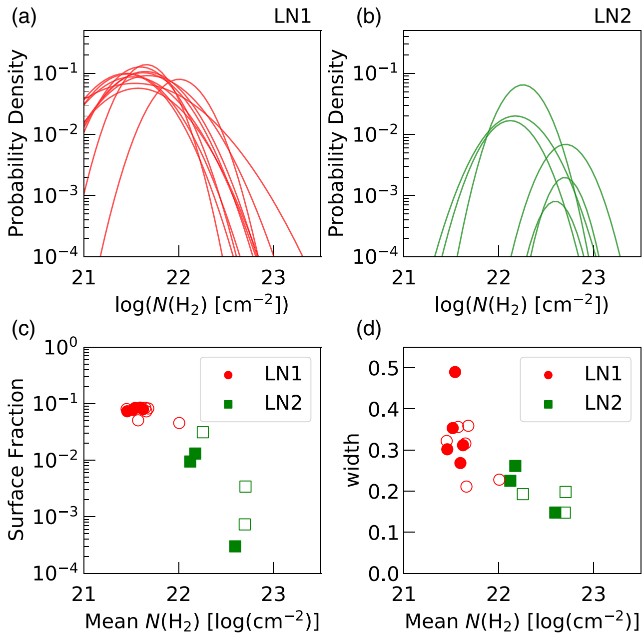


**Figure 3.** (a) and (b): the best-fit curves of 11 clouds for the LN1 and LN2, respectively. (c) and (d): correlation diagrams between the mean $N(H_2)$ and surface fraction, and (d) between the mean $N(H_2)$ and half-width of LN components, respectively. The circles and squares indicate LN1 and LN2, respectively. The filled symbols indicate the clouds of which the completeness limit contours were closed, and the open symbols indicate the other clouds.

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