Probing the Evolution of Molecular Cloud Structure
Kainulainen, J.\(^{(1)}\), Beuther, H.\(^{(1)}\), Henning, T.\(^{(1)}\), Plume, R.\(^{(2)}\)

\(^{(1)}\) Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
\(^{(2)}\) Department of Physics and Astronomy, University of Calgary, 2500 University Drive NW, Calgary, Alberta T2N 1N4, Canada

Abstract
We have derived large-scale dust column density maps for a complete set of nearby molecular clouds using a near-infrared extinction mapping technique. With these data, we performed the first systematic study of column density probability distributions in molecular clouds. We found that the probability density functions (PDFs) of non-star-forming clouds are almost always well-fitted by lognormal functions, while the PDFs of star-forming clouds always show deviations from this shape at higher column densities. This can be interpreted as evolutionary sequence of cloud structure, in which quiescent clouds are decisively shaped by turbulent motions, but the role of turbulence decreases significantly prior to the onset of active star formation.

Introduction
Stars form in the most extreme density enhancements of molecular clouds. In the current view, the overall structure of molecular clouds is crucially affected by turbulent motions, driven at scales larger or comparable to the cloud complexes (up to hundreds of parsecs). The predictions of such self-organised turbulent flows have been connected to analytic theories of star formation, leading to a picture of turbulence-regulated star formation. In this framework, one particularly important characteristic is the probability distribution of gas densities. This distribution is expected to take a lognormal shape in isothermal, turbulent media not significantly affected by the self-gravity of gas (e.g. [5, 7]). The function is used to explain, e.g. the initial mass function of stars, and the star formation rates of molecular clouds (e.g. [4]). Most importantly from the observational point of view, the predicted lognormality of this distribution is reflected also in the column density probability distributions of molecular clouds (e.g. [3, 7]).

Extinction maps of nearby clouds
To connect these predictions to the observed column density structure of molecular clouds, we examined the column density structure of nearby clouds via near-infrared extinction mapping technique.

The sample:
We selected from the literature all prominent cloud complexes that are closer than \(r < 200\) pc, resulting to a sample of \(\sim 25\) molecular clouds. For comparison, we also included in the study some well-known complexes at the distances of \(200 \ldots 500\) pc.

The NICEST method:
We employed a near-infrared color-excess mapping technique NICEST [2] in conjunction with photometric data from 2MASS to derive dust column density maps for the clouds in the sample [1]. In NICEST, the near-infrared colours of stars shining through molecular clouds, are compared to the colours of stars in a nearby field that is free from extinction. This comparison yields estimates of a NIR extinction towards the stars in the molecular cloud region. The maps were computed in the common physical resolution of \(0.1\) pc (\(\sim 2\) \(\alpha\)), and they probe column densities of \(N \approx 1 \ldots 200\) \(10^{22}\) \(\text{cm}^{-2}\).

To summarize, the resulting data set forms the most comprehensive view of the large-scale column density structure of molecular clouds today (examples given in Fig. 1).

Column density PDFs
Figure 2 shows 12 PDFs to illustrate the PDFs derived for the clouds in our sample. The panels show also fits of lognormal functions to the distributions. From the PDFs, two features can be seen. (1) The PDFs are almost never well-fitted with a simple lognormal function. Rather, they often show a power-law-like deviation at high-mass side. (2) In almost all clouds, the peak of the distribution is well-fitted by a lognormal function, the shape commonly predicted for non-gravitating turbulent flows.

Star-forming vs. quiescent clouds:
Our cloud sample consists of both active star-forming clouds and clouds without any star formation. Intriguingly, we find a clear difference in the PDFs between these groups. The PDFs of quiescent clouds are almost always well-fitted by lognormal functions, while star-forming clouds always show a power-law-like deviation from this shape (see Fig. 3). This trend is also reflected in the cumulative forms of the PDFs (Fig. 4) that show how star-forming clouds systematically contain higher amount of material at high column densities compared to non-star-forming clouds.

Discussion
In the framework of turbulence-regulated star formation, the observed differences between quiescent and star-forming clouds can be interpreted as an evolutionary sequence. The young clouds are dominantly shaped by turbulent motions, and thereby their PDFs resemble closely the shape predicted for non-gravitating turbulent flows. However, during their evolution they accumulate a growing fraction of material to higher column densities, with star formation taking place at some stage of this sequence. In the state of active star formation, the dominant role of turbulence is restricted to low column densities. Interestingly, the transformation from turbulence-dominated PDFs to PDFs with power-law-like tails must occur rapidly following the onset of active star formation, or even prior to it. This is due to the lack of star-forming clouds that have lognormal PDFs.

References