We compute the structure function scaling of a 2MASS extinction map of the Taurus molecular cloud complex. The scaling exponents of the structure functions of the extinction map follow Boldyrev’s velocity structure function scaling of supersonic turbulence. This confirms our previous result based on a spectral map of $^{13}$CO $J = 1–0$ covering the same region and suggests that supersonic turbulence is important in the fragmentation of this star-forming cloud.

Subject headings: dust, extinction — ISM: kinematics and dynamics — turbulence
the mixture of stars and other clouds in their background. The Taurus molecular cloud complex is far from the Galactic plane (approximately 15° south) and very close to us, at a distance of approximately 140 pc (Kenyon, Dobrzycka, & Hartmann 1994). Contamination from foreground stars is therefore negligible for this region, as well as confusion with other clouds in the distant background. Arce & Goodman (1999) have previously studied the stellar extinction in Taurus, but their work is limited to a very small region of the molecular cloud and a narrow range of values of visual extinction.

We have computed extinction maps of the Taurus molecular cloud complex using 1, 3, 10, 30, and 100 stars per cell covering a region of 12° × 10°. Figure 1 shows the map obtained with 10 stars per cell. Approximately 115 known young embedded stars (Herbig & Bell 1988; Leinert et al. 1993; Kenyon et al. 1994; Briceño et al. 1998) have been excluded from the 2MASS catalog before computing the extinction maps. The intrinsic color is computed as the median color of stars in regions where no gas-to-dust ratio, \( N(H + H_2)/A_v = 2 \times 10^{21} \text{ cm}^{-2}\text{ mag}^{-1}\) (Bohlin et al. 1978), the range in extinction corresponds to approximately 2 orders of magnitude in column density, from \( N(H + H_2) = 6 \times 10^{20} \text{ cm}^{-2}\) to \( N(H + H_2) = 6.6 \times 10^{22} \text{ cm}^{-2}\).

### Table 1

| Number of Stars | \( \sigma_{AV} \) (mag) | Median Resolution (arcmin) | \( A_{V \text{ max}} \) (mag) |
|-----------------|------------------------|----------------------------|-----------------------------|
| 100             | 0.26                   | 12.4                       | 8.0                         |
| 30              | 0.34                   | 6.7                        | 11.7                        |
| 10              | 0.49                   | 3.4                        | 19.5                        |
| 3               | 0.85                   | 1.7                        | 26.3                        |
| 1               | 1.30                   | 1.0                        | 32.7                        |

### 3. Structure Functions of Projected Density

The structure functions of the extinction map, \( A_v(x) \), are defined as

\[
S_p(l) = \langle |A_v(x) - A_v(x + l)|^p \rangle,
\]

where \( p \) is the order, \( l = |I| \), and the average is extended to all map positions \( x \) and all directions of \( I \). In turbulent flows, it is found that the structure functions of velocity are power laws. Assuming that the structure functions of projected density (or extinction) are power laws as well, we call \( \eta(p) \) the exponents of these power laws:

\[
S_p(l) \propto l^{\eta(p)}.
\]

In Figure 2, we have plotted the structure functions of the map obtained with 10 stars per cell, relative to the third-order structure function, since we are interested in investigating the relative scaling, \( \eta(p)/\eta(3) \) (this follows the idea of extended self-similarity by Benzi et al. 1993 and Dubrulle 1994). Errors in the structure function values introduced by the statistical uncertainty in the extinction map have been estimated by computing the structure functions of new maps, obtained from the

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**Fig. 1.—Extinction map of the Taurus region computed with 10 stars per cell.**

**Fig. 2.—Structure functions of the extinction map from \( p = 1 \) to 20 (bottom to top) relative to the third-order structure function. Different points along each function correspond to different values of \( l \). The extinction map with 10 stars per cell has been used. The solid lines show the least-squares fits used to define the power-law slopes.**
original one by adding noise at the 1 \sigma level (0.49 mag in the map with 10 stars per cell). Error bars are smaller than the diamonds in Figure 2 and are therefore not shown.

The function $\eta(p)/\eta(3)$ is plotted in Figure 3. The velocity scaling predicted by Boldyrev (2002) for supersonic turbulence is shown as a solid line, the one predicted by She & Lévêque (1994) for incompressible turbulence is plotted as a dashed line, and Kolmogorov’s velocity scaling, $p/3$, is shown by the dotted line (Kolmogorov 1941). The scaling of the structure functions of projected density is found to be the same as the scaling of velocity structure functions in supersonic turbulence. We regard it as the same as that of the velocity; the velocity scaling from theoretical models is shown here only as a reference.

Padoan et al. (2003) have recently analyzed in a similar way $^{13}$CO maps of the same Taurus region and of Perseus. The present result for the relative scaling of the structure functions in Taurus confirms the results of that work. However, the sample size from the 2MASS data is much larger than the sample size of the $^{13}$CO map. Furthermore, the spatial resolution of the extinction map is slightly better and the range of column density sampled 20 times larger than in the $^{13}$CO map. The statistical significance of high-order moments from the analysis of the 2MASS data should therefore be much higher than from the $^{13}$CO maps.

4. CONCLUSIONS

Boldyrev (2002) has recently proposed an analytic model for the velocity structure function scaling in supersonic turbulence. The model is an extension of the scaling of incompressible turbulence proposed by She & Lévêque (1994) and has already been successfully tested with numerical simulations of supersonic turbulence (Boldyrev, Nordlund, & Padoan 2002a). An equivalent analytic model for the scaling of the structure functions of projected density in supersonic turbulence is not available yet. Only the slope of the second-order structure function has been derived from the velocity structure functions, under certain approximations (Boldyrev, Nordlund, & Padoan 2002a). However, the fact that the projected density follows the same scaling as the velocity field in supersonic turbulence suggests that the density field in the Taurus region is the result of a multiplicative process with a log-Poisson statistics (Dubrulle 1994), very likely the result of the turbulent fragmentation.

The importance of supersonic turbulence in the fragmentation of star-forming regions has been established in previous works (e.g., Padoan & Nordlund 1999, 2002; Padoan et al. 2001). The purpose of the present work is primarily to determine the statistical properties of the fragmentation process, independent of its origin. Such statistical properties may be universal, for example, if they are mainly the consequence of turbulence or depend on several physical parameters, such as gas density, temperature, turbulent velocity dispersion, and star formation activity. We plan to compute and analyze 2MASS extinction maps of different extended star-forming regions in order to establish the properties of the fragmentation process that leads to the formation of stars in different environments.

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