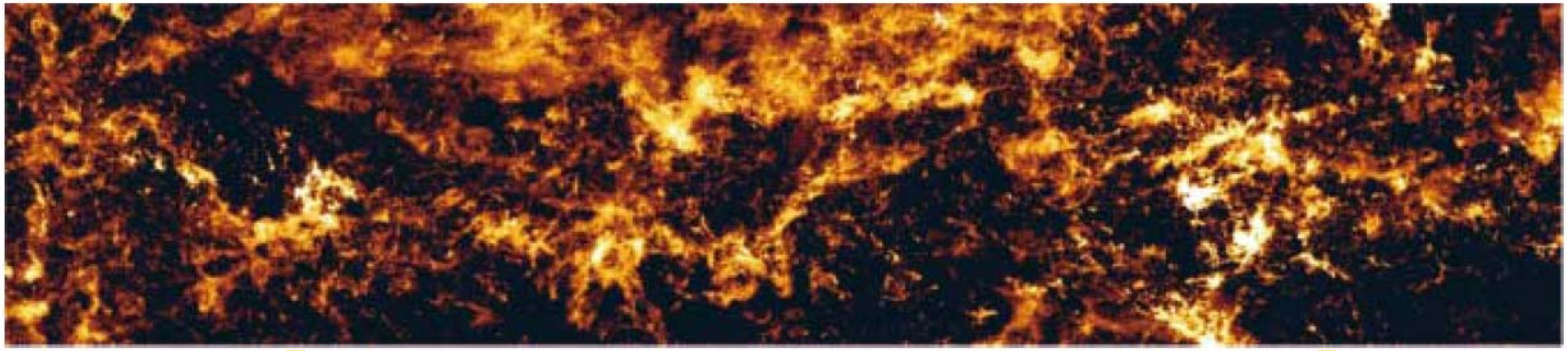
Density Distribution Functions in Supersonic Turbulence

Hyunjin Cho, Hyesung Kang, Pusan National Univ.
Dongsu Ryu, Chungnam National Univ.
Jongsoo Kim, Korea Astronomy & Space Science Institute

Turbulent Molecular Clouds

Heyer et. al(1998)

Figure 1 ^{12}CO emission from the outer Galaxy spanning a range of Galactic longitude from 102.5° to 141.5° and latitude from −3° to 5.4°, sampled every 50″ with a 45″ beam. The emission is integrated between −110 km s^{-1} and 20 km s^{-1}. The high latitude emission is mostly from local gas at low velocity, consisting of small struc-
mbination
s arm gas
that excite
chical and
e same on
M. Heyer



Complex , unpredictable behavior

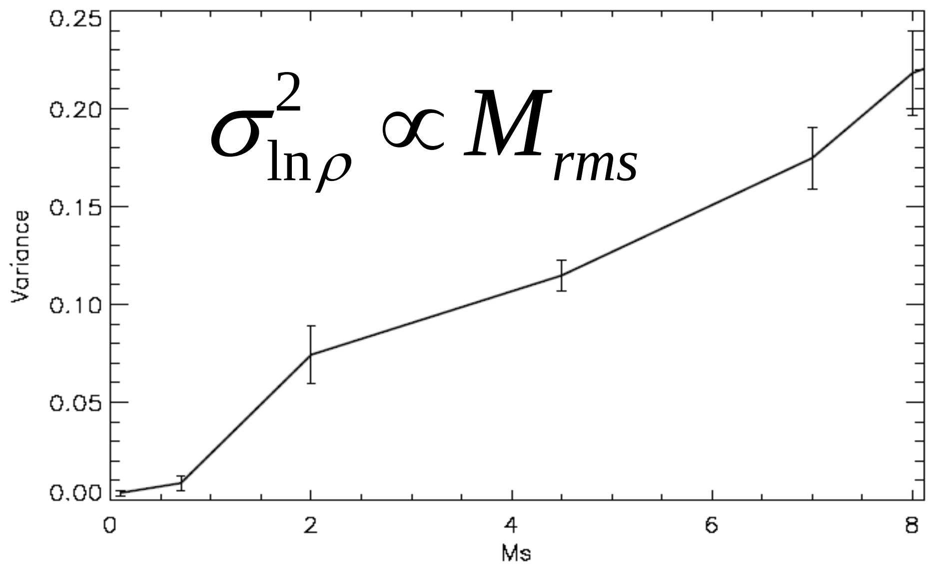
Turbulence exist on various scale of astrophysical environments.

- ❖ Molecular cloud of star forming region
- ➔ Initial Mass Function, Star Formation Rate
- ❖ SNR shock interacting with ISM
- ❖ Star & ISM distribution of our galaxy
- ❖ Large scale structure

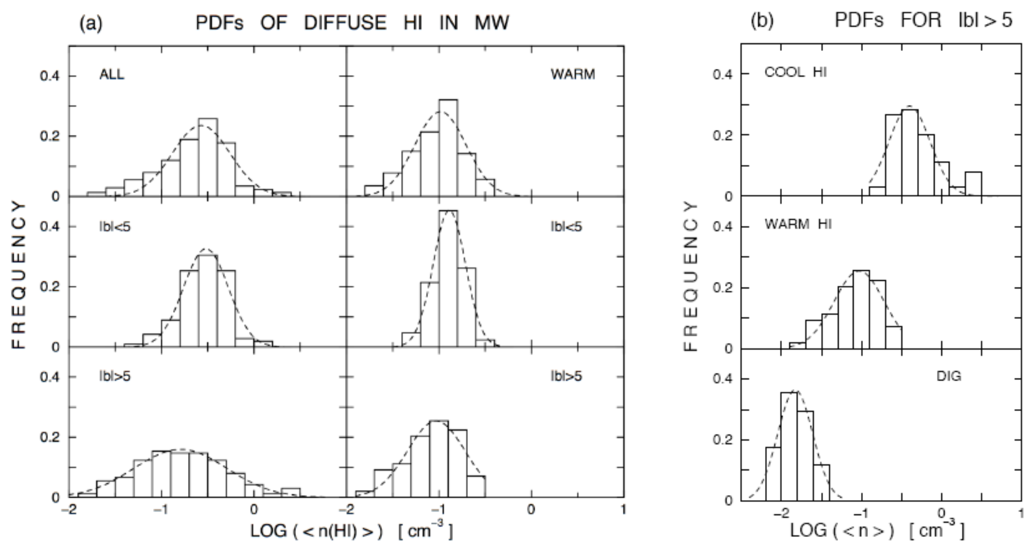
Theoretical analysis of turbulent flow need statistical methods in the present study.

- ❖ Probability Distribution Function (PDF)
- ❖ Structure Function (SF)
- ❖ Power Spectrum (PS) etc.

Observed Properties of Turbulence in ISM



$$\sigma^2_{\ln\rho} \propto M_{rms}$$



❖Burkhart et. al. (2009)

variance of PDF– Mach number relation of turbulence in Small Magellanic Cloud (SMC)

❖ Berkhuijsen & Fletcher (2011)

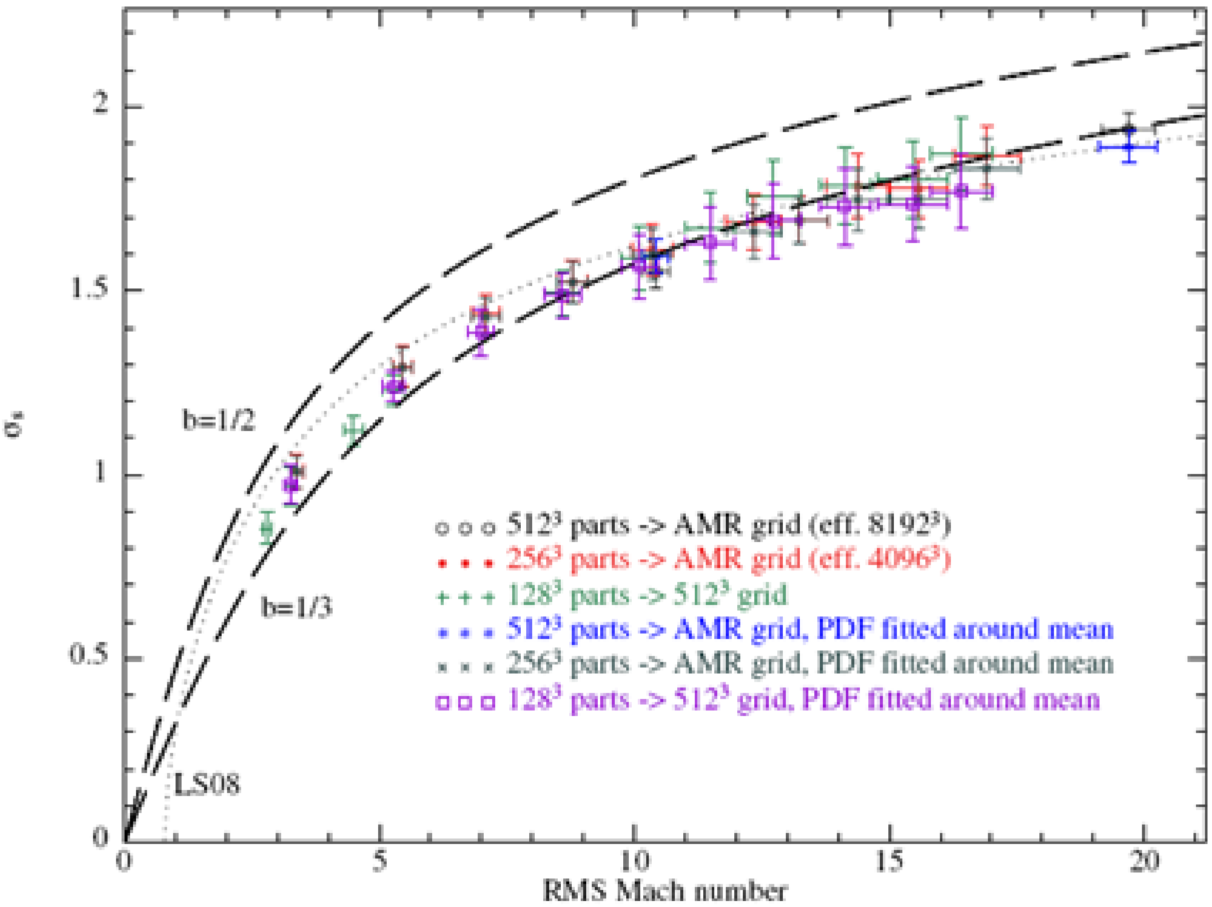
PDF in the neutral and ionized gas of the molecular cloud on the Galactic plane.

➔ Lognormal distribution

$$P(\ln\rho) = \frac{1}{\sqrt{2\pi\sigma^2_{\ln\rho}}} \exp\left[\frac{-(\ln\rho - \mu)^2}{2\sigma^2_{\ln\rho}}\right]$$

Lognormal distribution of density

MHD Simulations of Supersonic, Isothermal Turbulence



❖ Price, Federrath, Brunt (2011)

dispersion of PDF of $\ln \rho$

versus rms Mach no.

$$\sigma_{\ln \rho} \sim \sqrt{\ln(1+b^2 M_{rms}^2)}$$

Padoan et. al. (1997) : b ~0.5

Passot & Vazquez-Semadeni (1998)
: b ~ 1

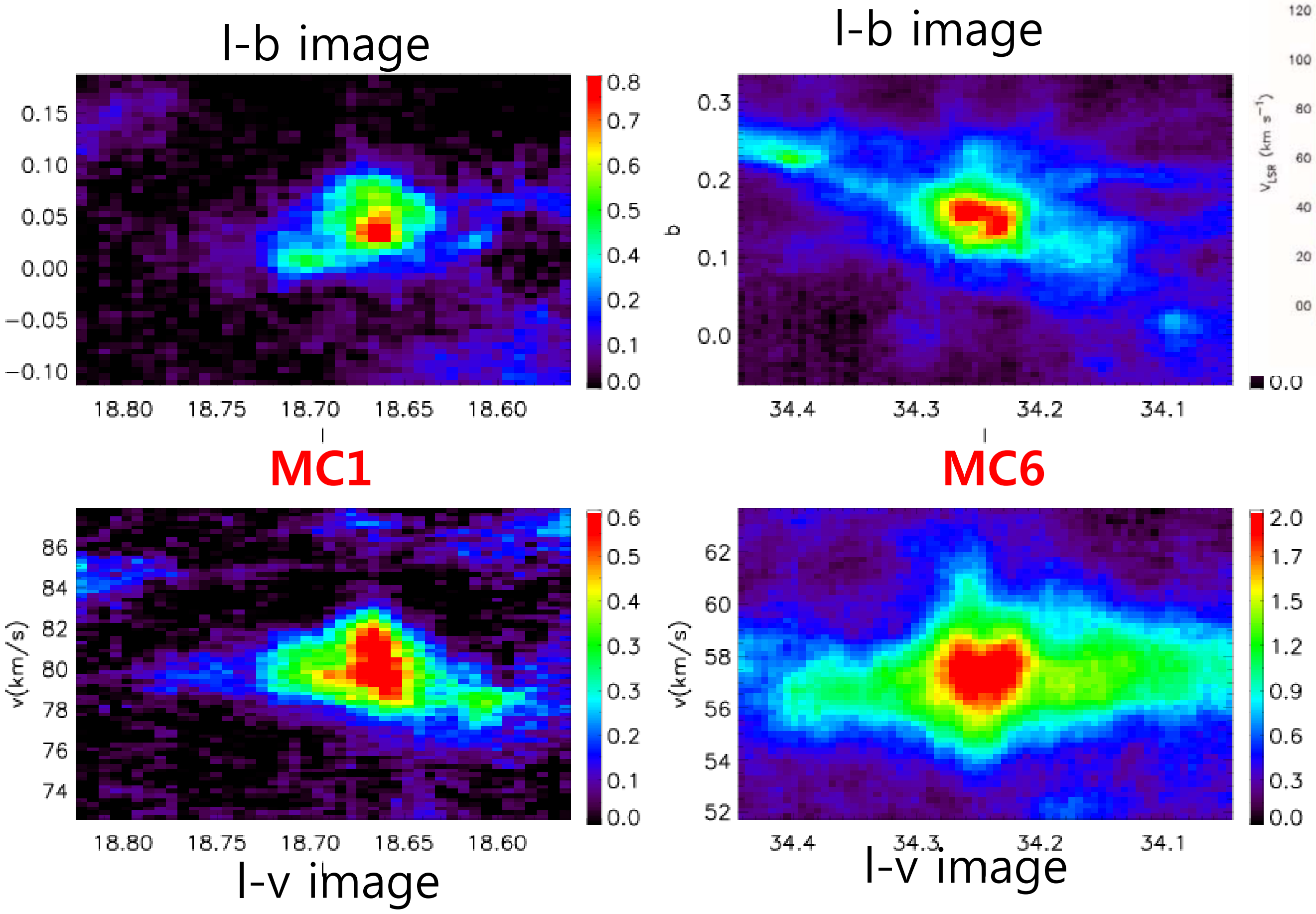
Kritsuk et. al (2007) : b ~ 0.26

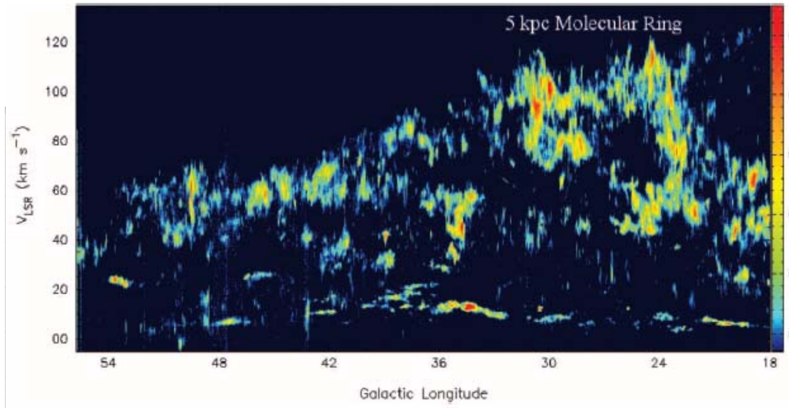
$$P(\ln \rho) = \frac{1}{\sqrt{2\pi\sigma_{\ln \rho}^2}} \exp\left[\frac{-(\ln \rho - \mu)^2}{2\sigma_{\ln \rho}^2}\right]$$

Lognormal distribution of density

Turbulence in Molecular Clouds in GRS data

The Boston University - FCRAO Galactic Ring Survey (GRS)
: ^{13}CO (J=1→0) Observation covering wide longitude range Jackson et. al. (2006)





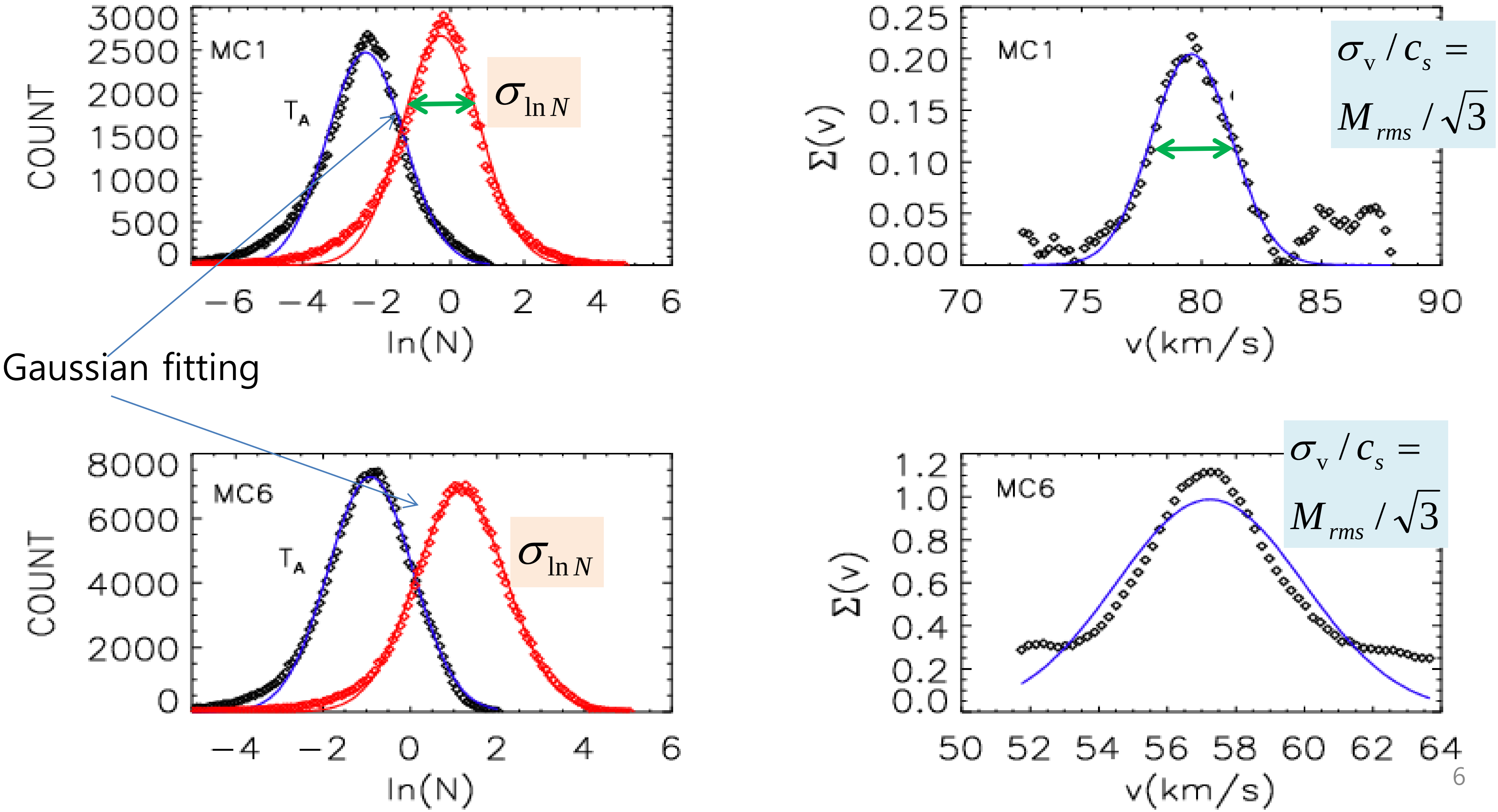
We select 9 molecular clouds.

- concentrate on molecular cloud core

$$N^{13}CO(l,b,V) \propto T_A(l,b,V): \ \text{so} \ \sigma_{\ln T_A} \sim \sigma_{\ln N}$$

observed Antenna Temperature ⇒ column density of gas in a velocity channel along a line of sight

Density Distribution **Velocity Distribution**



Numerical Simulation for Supersonic MHD Turbulence

3-dimensional MHD simulation based on TVD scheme (Kim et al. 1999)

512 cube, isothermal gas, Large and Small injection scale turbulence

Mach number (M_{rms} = 1, 2, 4, 7)

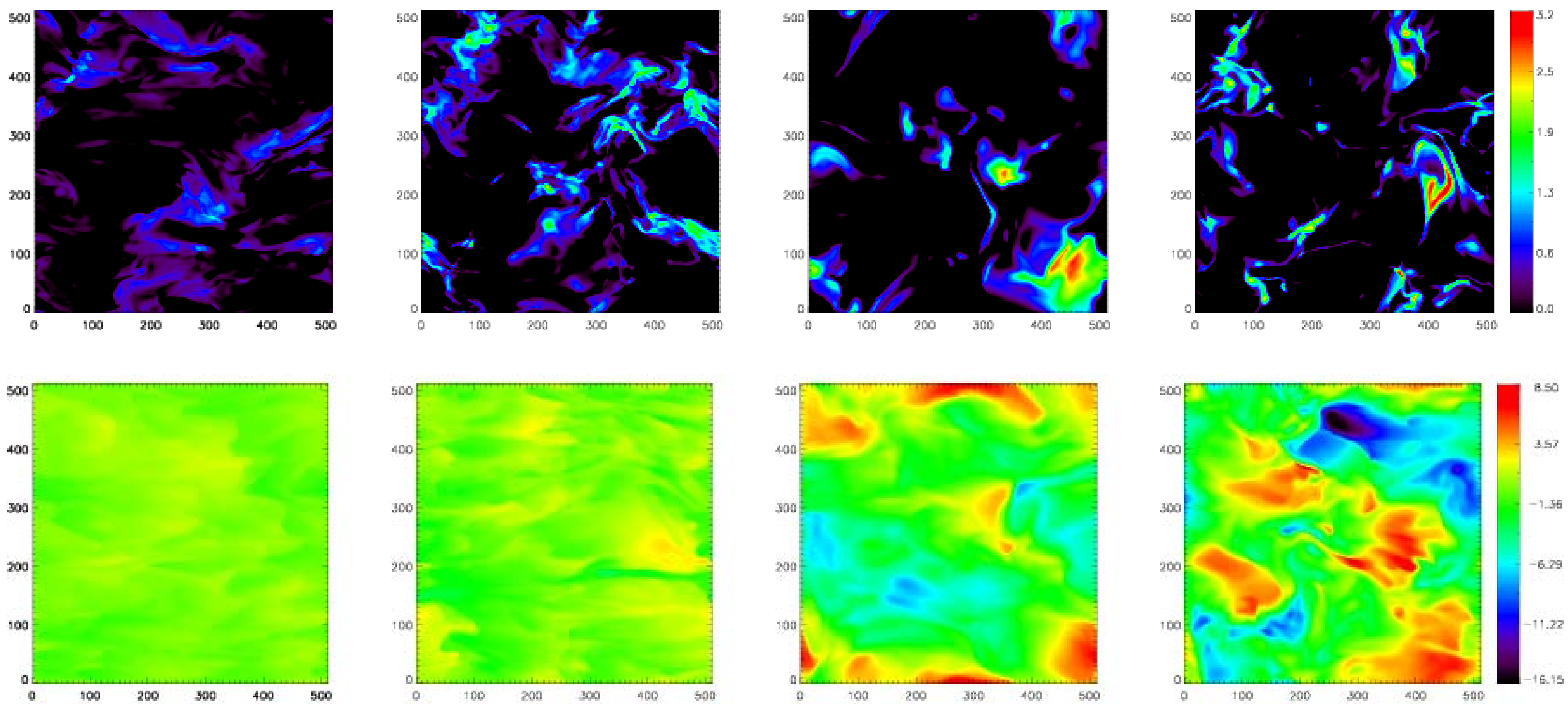
Magnetic field (β = 0.1, 1, 10)

injection scales

$$L_{inj} \sim L/2$$

$$L_{inj} \sim L/16$$

Ms = 1 Ms=2 Ms=4 Ms=7



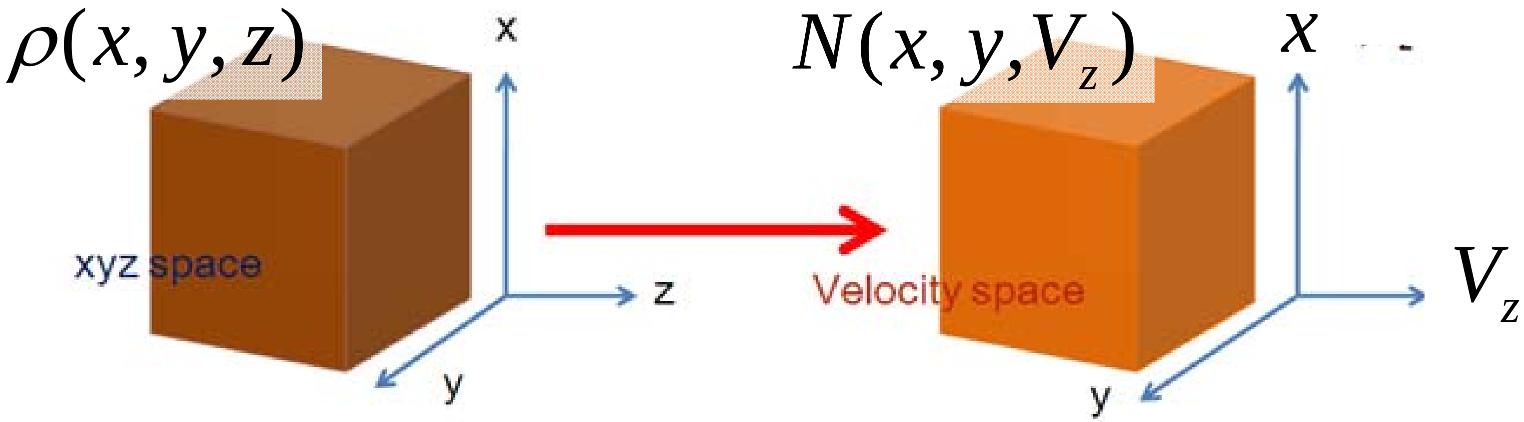
Density

Velocity

$$\beta = \frac{P_g}{P_B} = 1$$

Dense core formation ↑

Construction of column density in a velocity channel

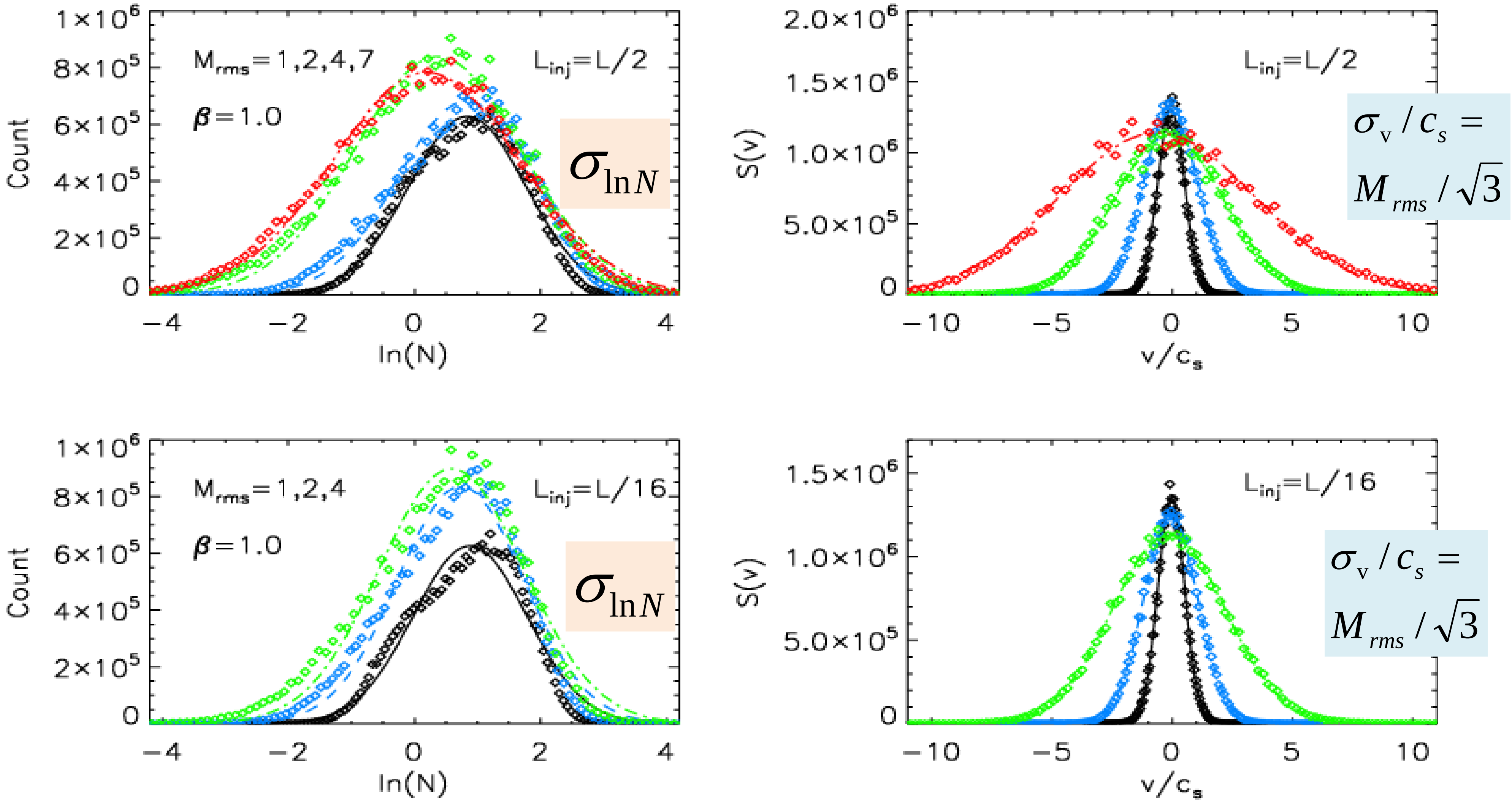


In order to compare the distribution of $\ln T_A(l, b, V)$ in observed MCs with that of the column density $\ln N(x, y, V_z)$ from the simulations.

$$\mathcal{N}(x_1, x_2, v_3) = \sum_{x_3} \rho(x_1, x_2, x_3) \cdot \Delta x_3 \quad \text{for } [v_3, v_3 + dv_3],$$

We calculate the column density in a velocity channel along the line-of-sight from the gas density in the simulation data cube.

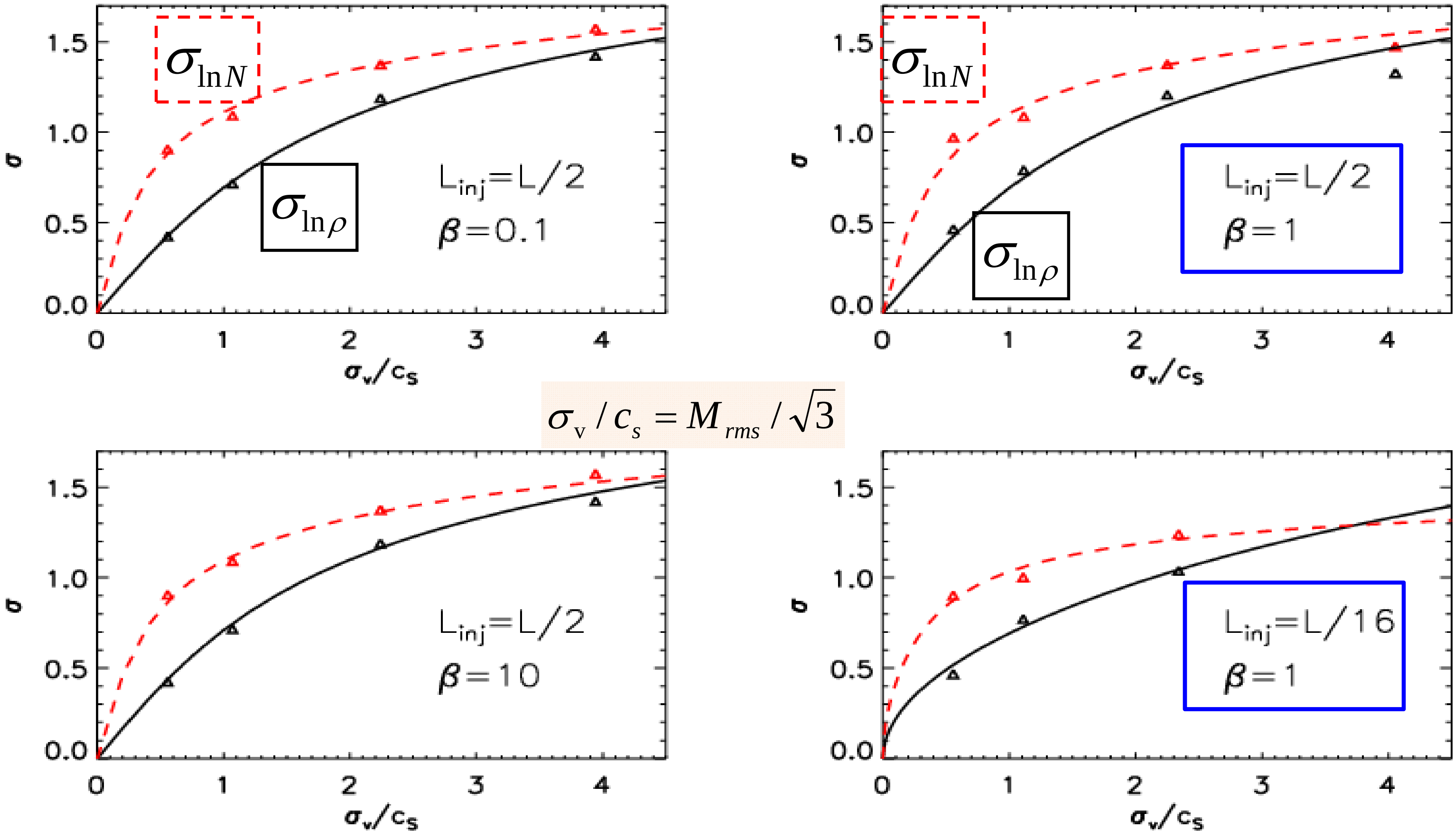
Column density and Velocity Distribution : Large Scale Forcing vs. Small Scale Forcing



Left : Density PDF
Solid lines: Gaussian fitting curves

Right : Velocity Distribution

Column density PDF-Velocity Relation in Turbulence Simulations

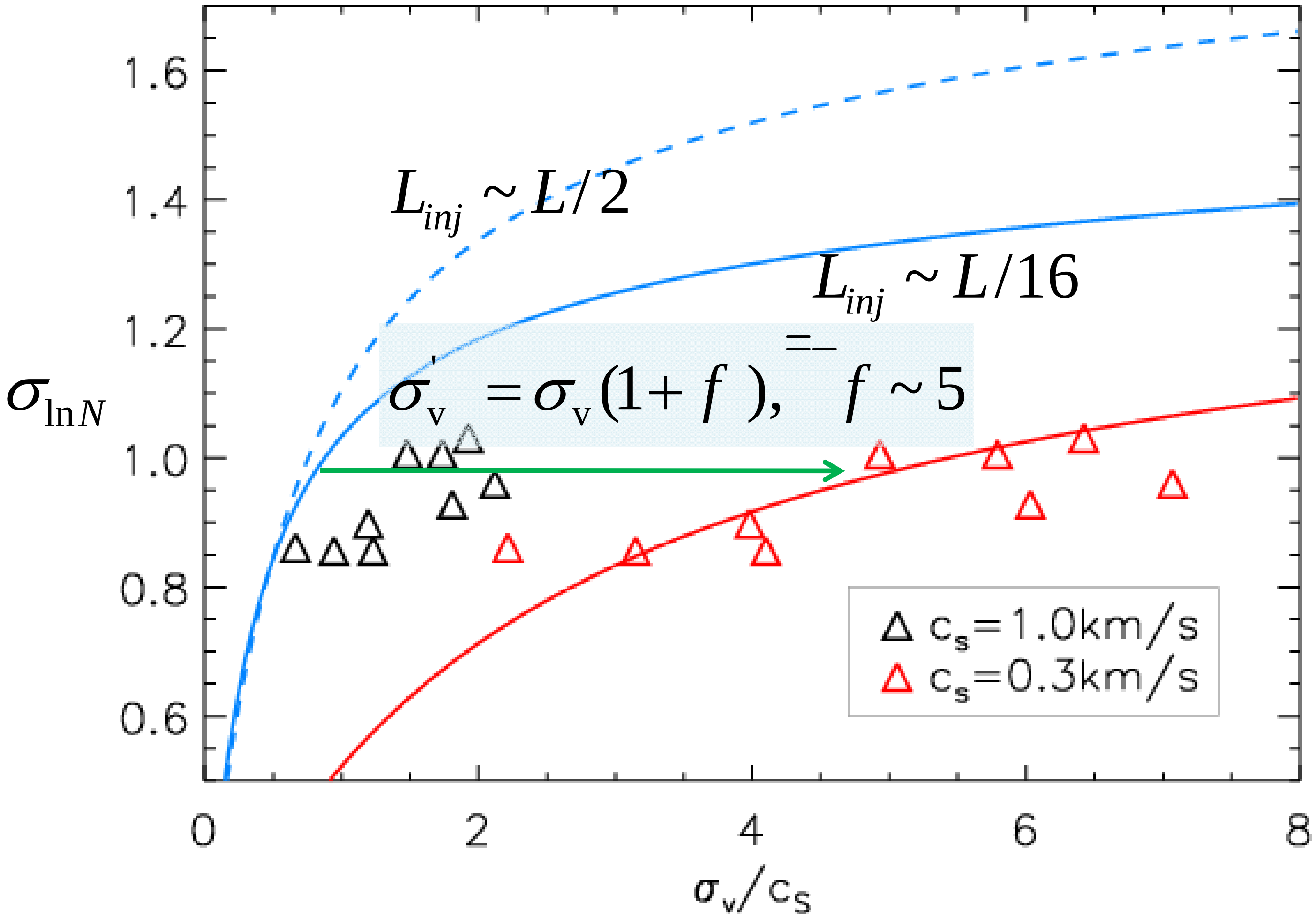


$$\sigma_v / c_s = M_{rms} / \sqrt{3}$$

$$\sigma_{\ln \rho} \sim a\sqrt{\ln(1+b^2(\sigma_v / c_s)^2)}$$

$$\sigma_{\ln N} \sim c\sqrt{\ln(1+d^2(\sigma_v / c_s)^2)}$$

Comparison of Simulation & Observation



Molecular cloud core

$T \sim 30K$

$c_s \sim 0.3 km/s$

Red & black triangles: values from GRS data

Red solid line: horizontal shift

❖Magnetic field (β = 0.1, 1.0, 10 is not important effect)
❖Small Scale Forcing is difficult to find consistent with the properties of observed turbulence.
❖e.g. Gravitational contraction may increase observed velocity dispersion

Summary

❖ Observation :

Turbulence in Molecular Clouds of GRS survey :

- relation of log(^{13}CO column density) distribution with velocity dispersion

➔ $$\sigma_{\ln N(^{13}CO)} \propto \sqrt{\ln\left(1 + a^2 (\sigma_v / c_s)^2\right)}$$

❖ Simulation :

3-dimensional MHD turbulence simulation

turbulence driven at different scales: $L_{inj} \sim L/2$ or $L_{inj} \sim L/16$

➔ $$\sigma_{\ln N} \sim c\sqrt{\ln\left(1 + d^2 M_{rms}^2\right)}$$

❖ Comparison of observation & simulation :

-turbulence driven at small injection scales might be more consistent with turbulence in molecular clouds.

- Gravitational contraction may increase observed velocity dispersion