Core formation rates of a MC and molecular line profiles of a core

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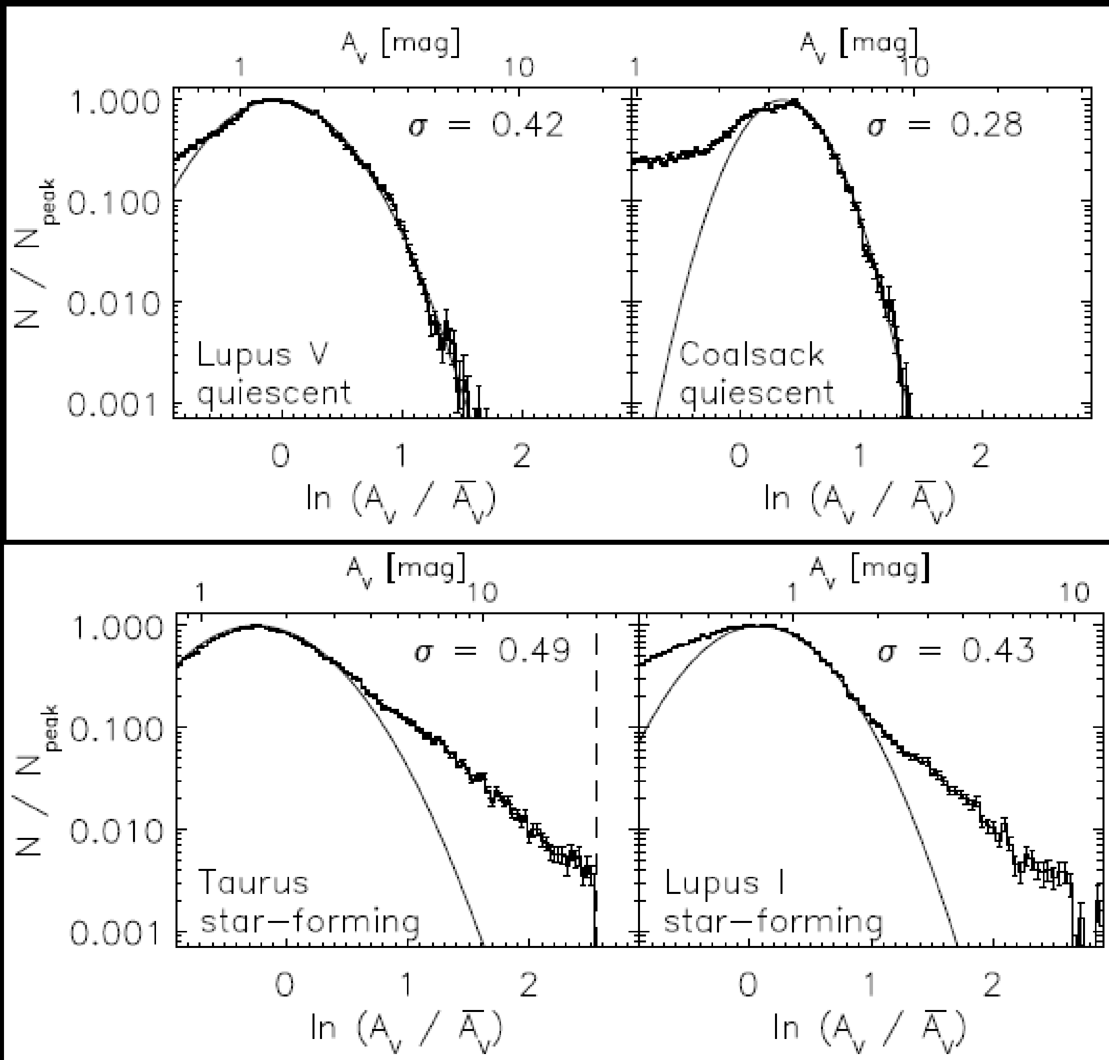
- Star (Core) Formation Rate in a molecular cloud (Cho & Kim 10)
- Molecular Line Profiles of a Collapsing Core (Lee & Kim 09)

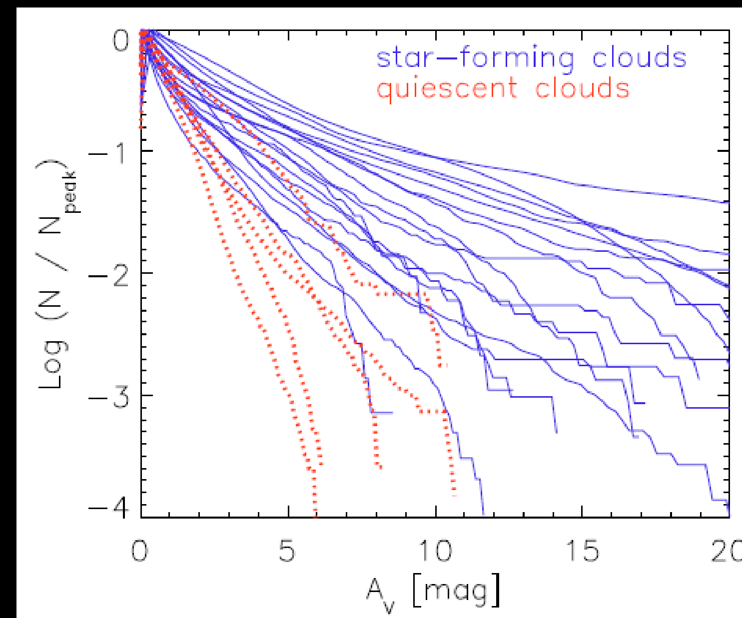
Motivation: SFR

- Density PDFs from isothermal (M)HD simulations without self-gravity have been successfully fitted with a lognormal function. (Vazquez-Samadei 94, Padoan et al. 97, ….)
- The lognormal density PDF has been one of important ingredients of star formation theories (e.g., Padoan & Nordlund 02; Hennebelle & Chabrier 08; Elmegreen 02, 08; Krumholtz & McKee 05).
- What are the effects of self-gravity on the density PDFs and SFR?

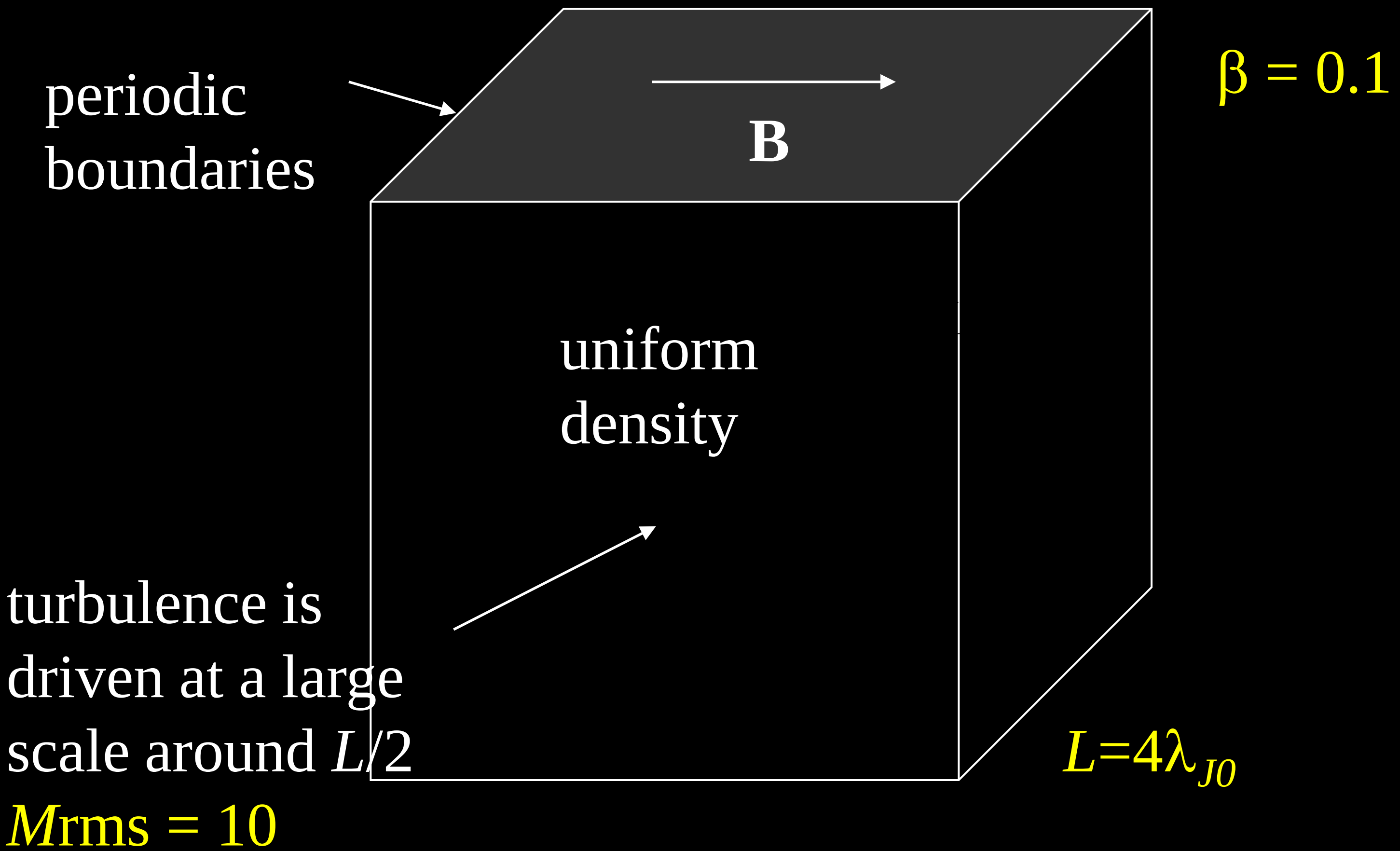
Kainulainen, Beuther, Henning & Plume (2009)

Av (column-density) PDFs



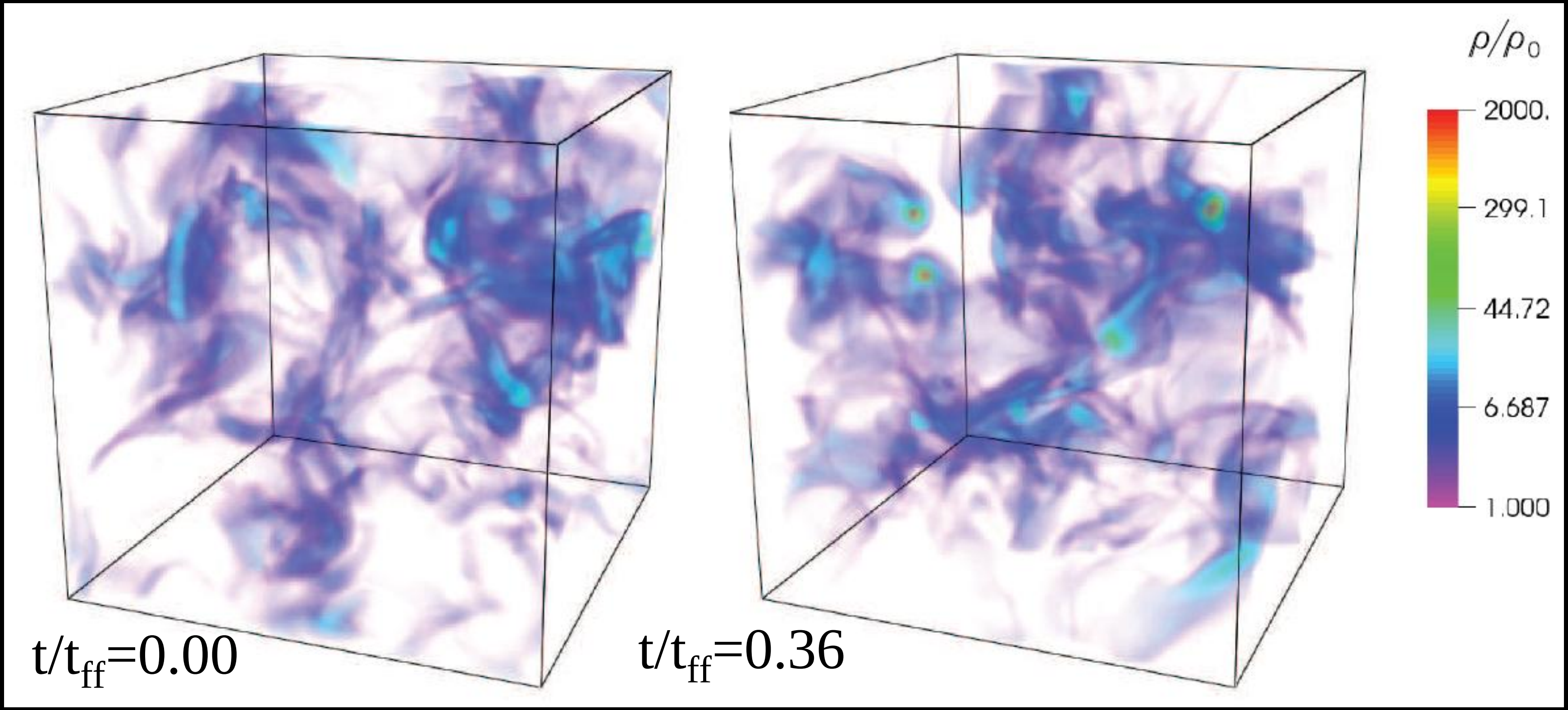


3D, isothermal, self-gravitating, driven MHD simulations



resolution: 512^3 cells

Density Fields



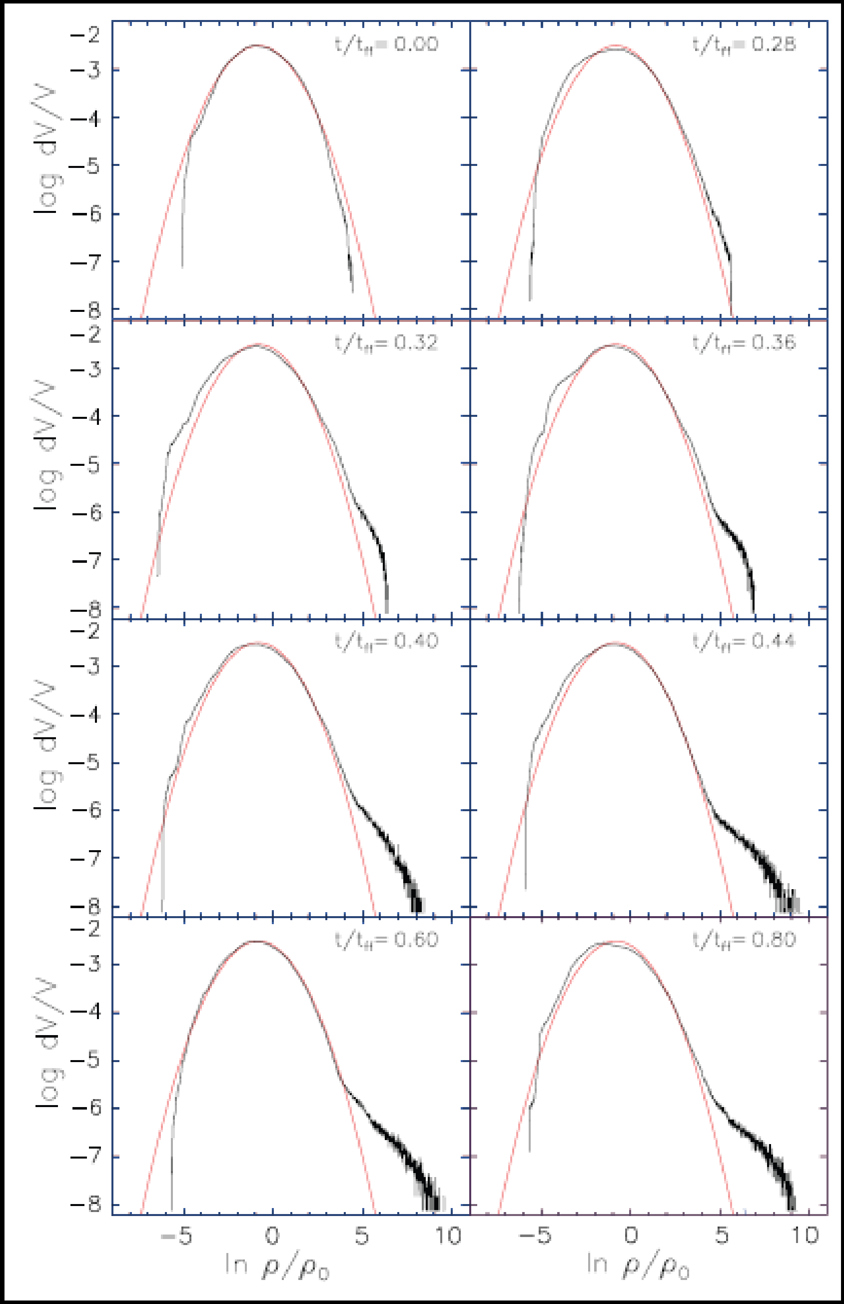
Density PDF evolution

- Log-normal distribution of density PDF before turning on self-gravity

$$p_{\rm LN}(s) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(s-\mu)^2}{2\sigma^2}\right]$$

$$s = \ln(\rho/\rho_0)$$

- Red lines: a log-normal fit to the averaged PDF of the converged state before turning on self-gravity
- As time goes on, a high density tail develops, which in fact increases the SFR.



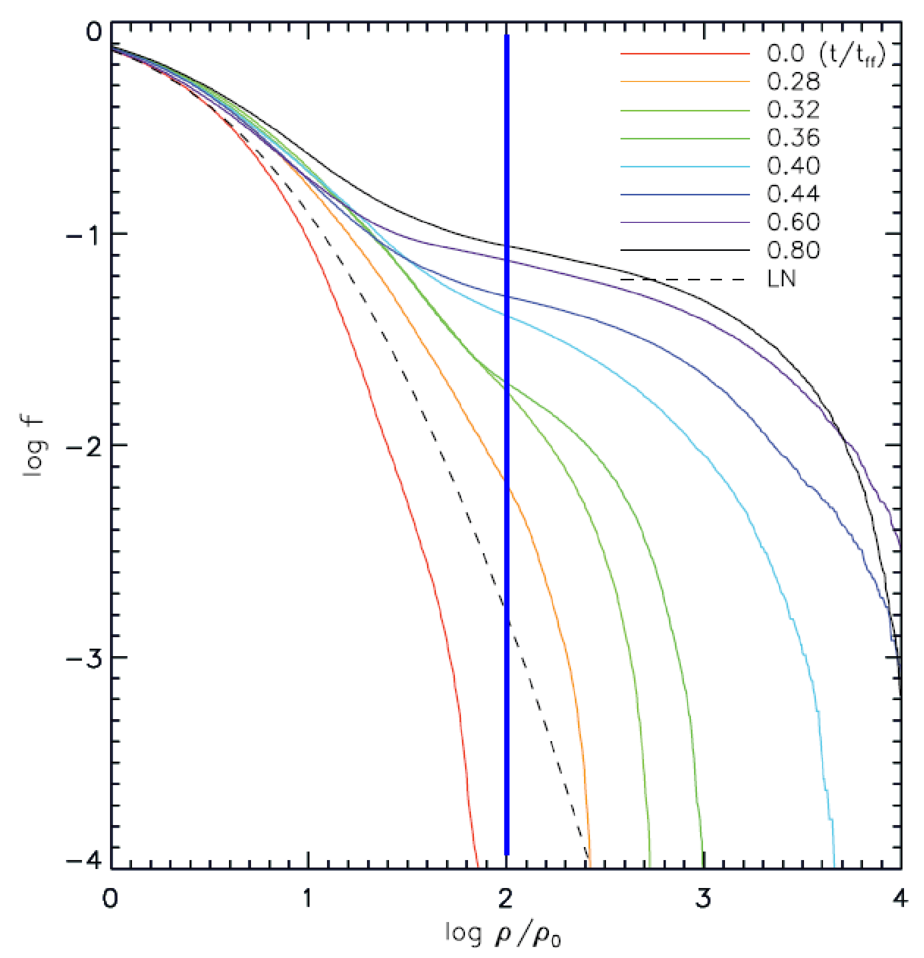
Cumulative Mass Fraction and CFR_{ff}

- Cumulative mass fraction

$$f(s) = \int_s^\infty \frac{\rho}{\rho_0} p(s) ds$$

$$s = \ln(\rho/\rho_0)$$

- Core (Star) formation rate per free-fall time $\mathrm{CFR}_{ff} = f(\rho_{cr})$
- CFR_{ff} with self-gravity is almost two-orders of magnitude larger than that from the LN distribution.
- SF theories (e.g., PN02, KM05, Elmegreen 02) based on the LN distribution should be modified.



Critical density for gas collapse

- Krumholtz & McKee (2005)

$$\lambda_J = \lambda_s \Rightarrow \frac{\rho_{cr}}{\rho_0} = \left(\frac{\lambda_{J0}}{\lambda_s}\right)^2 = \left(\frac{L}{4\lambda_s}\right)^2$$

$$25 \le \frac{\rho_{cr}}{\rho_0} \le 57$$

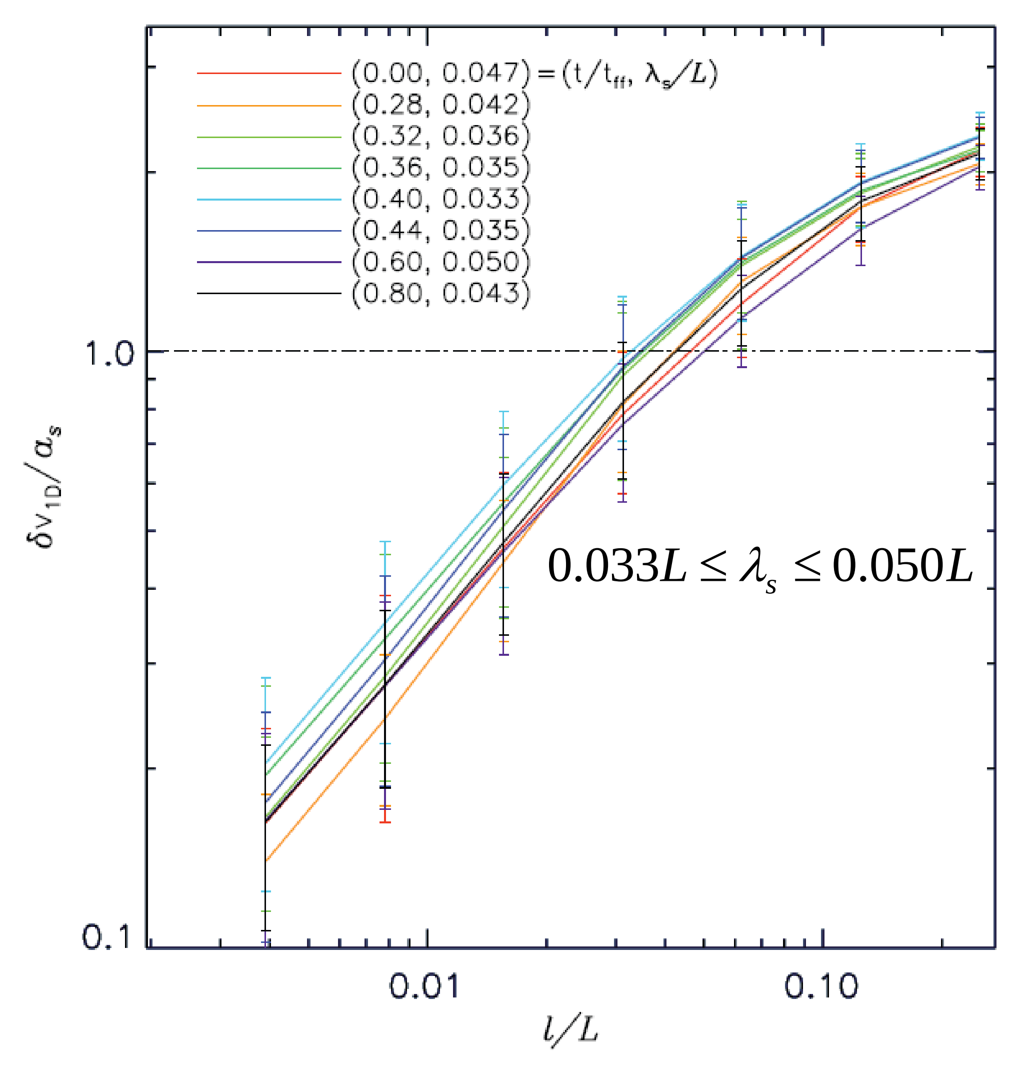
too small considering the fact that the density jump of M=10 flow is around 100

- Our choice:

$$100 \le \frac{\rho_{cr}}{\rho_0} \le 500$$

lower end: density jump of M=10

upper end: from observations of cores

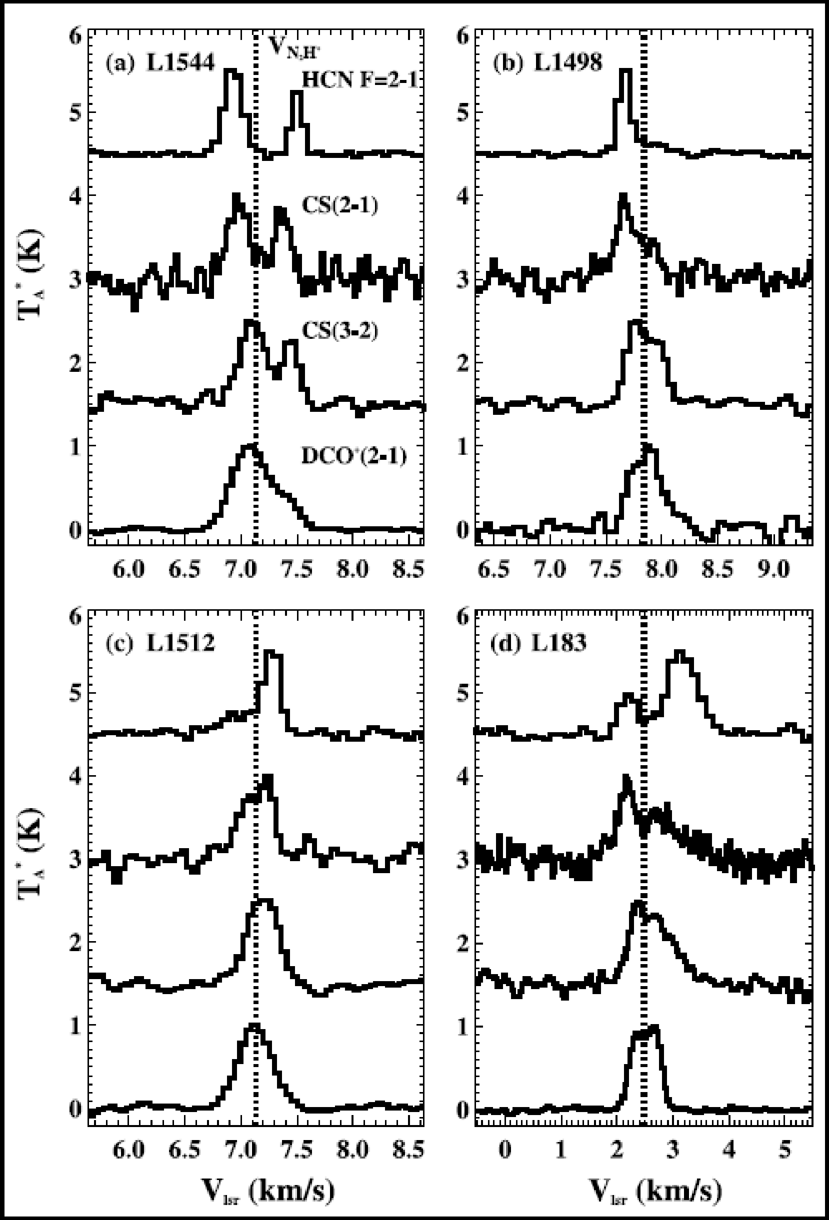


$$0.033L \le \lambda_s \le 0.050L$$

Molecular line profiles of starless cores

Motivation:

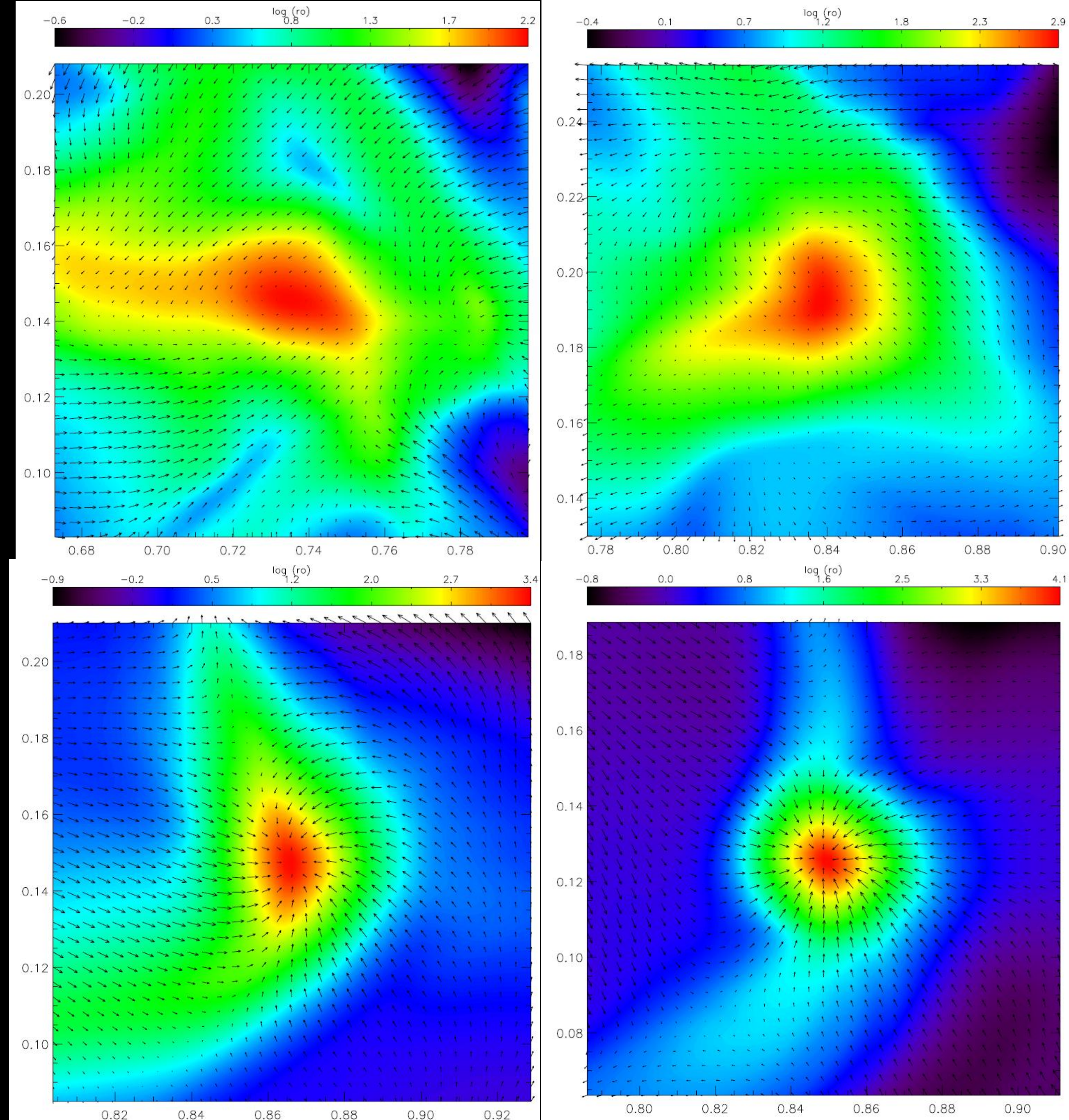
-How can we explain the change of line asymmetry shown in L183?



Sohn et al. (2007)

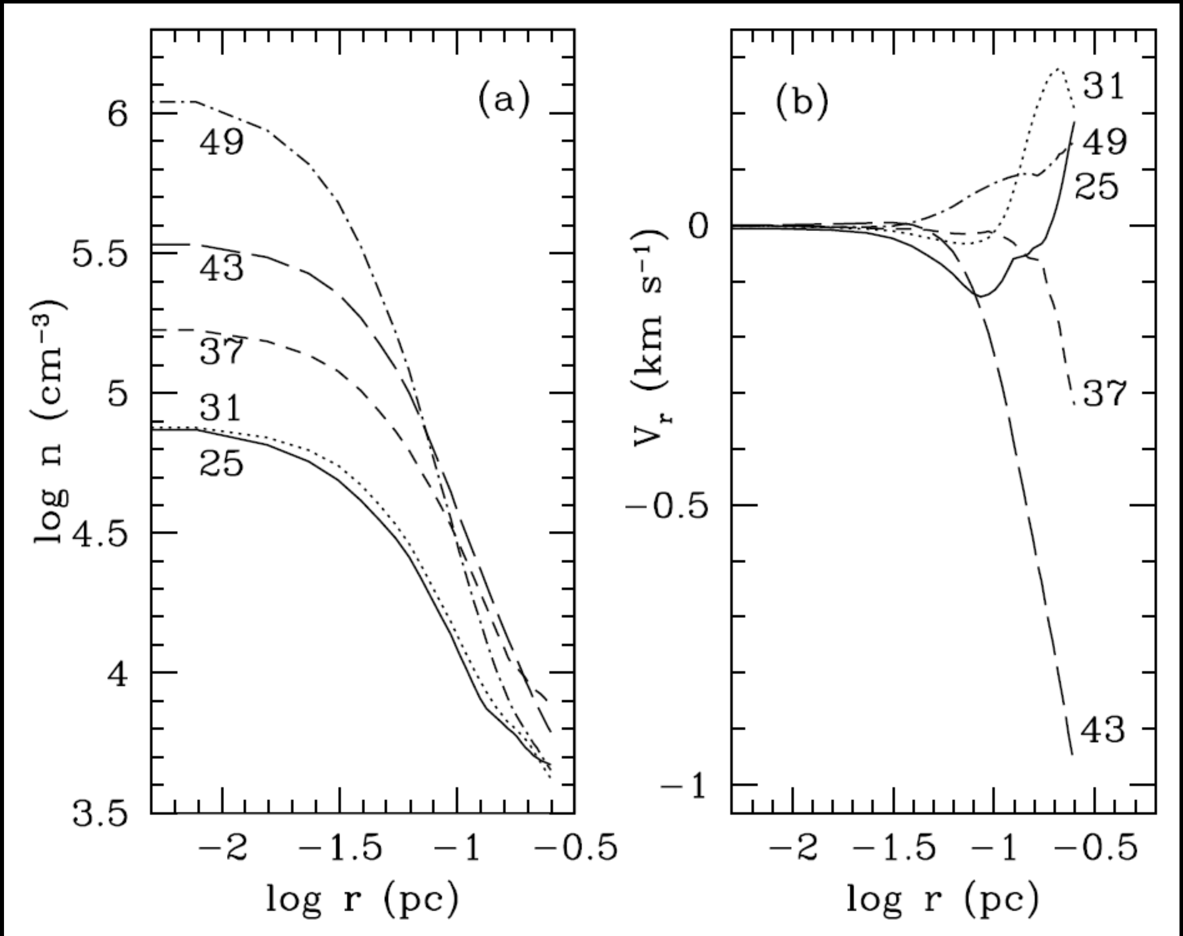
Sliced density and velocity fields at t=31,43,49,55x (40,000 years)

- Identify a core as a connected region whose $n > 10^3 cm^{-3}$
- Trace out the evolution of the core.
- The position of a density peak is taken as the origin of the radial coordinate.
- Subtract a center-of-mass velocity of the core from its velocity field.
- Take an radial average of the density and velocity fields of the core.

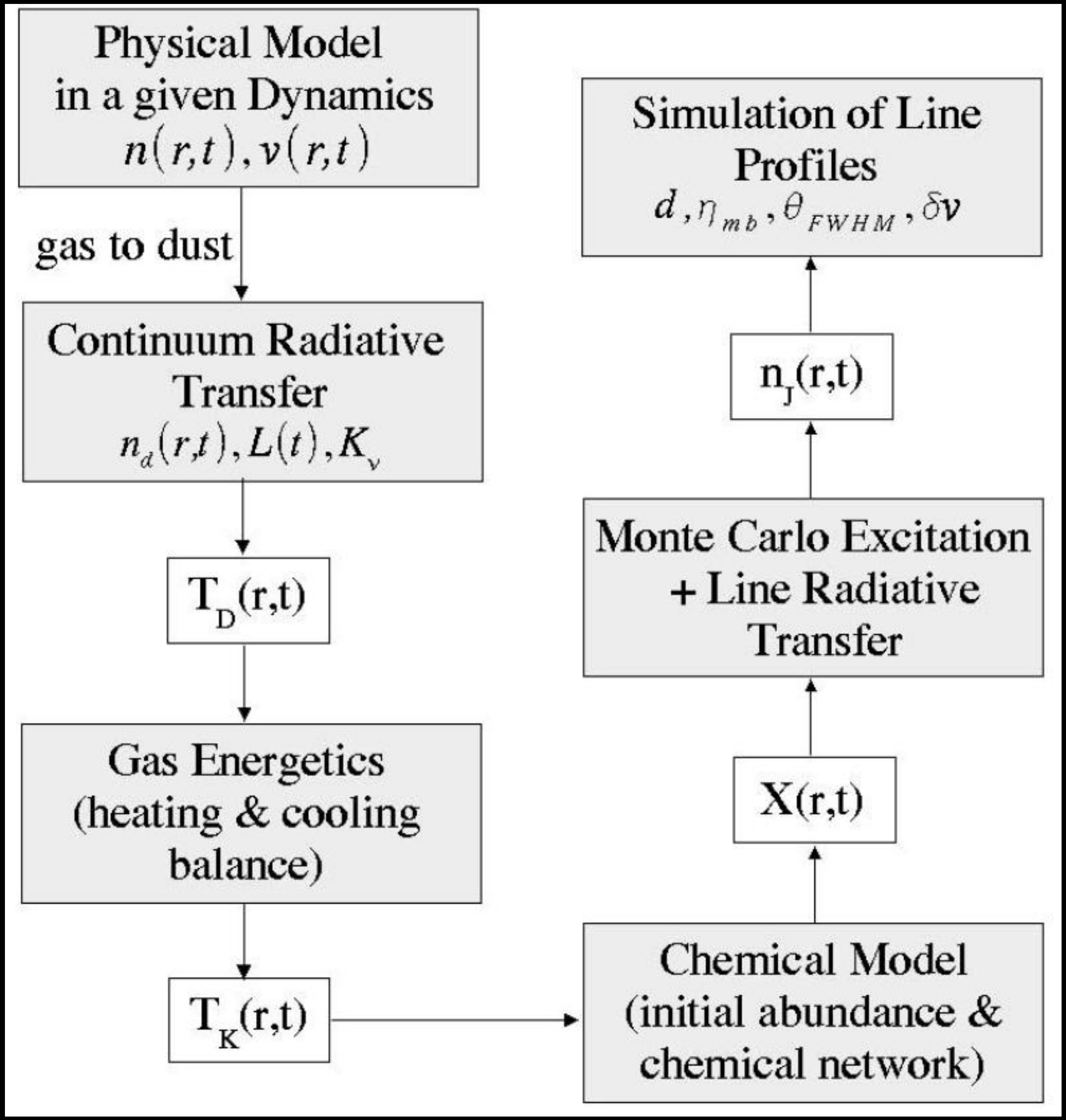


Radial density and velocity profiles

- The central density is increasing as time goes on.
- The power index of density profiles in the outer part is increasing from shallower than -2 to steeper than -2.
- The central part of the core is collapsing slowly.
- The outer part of the core is either collapsing or expanding.



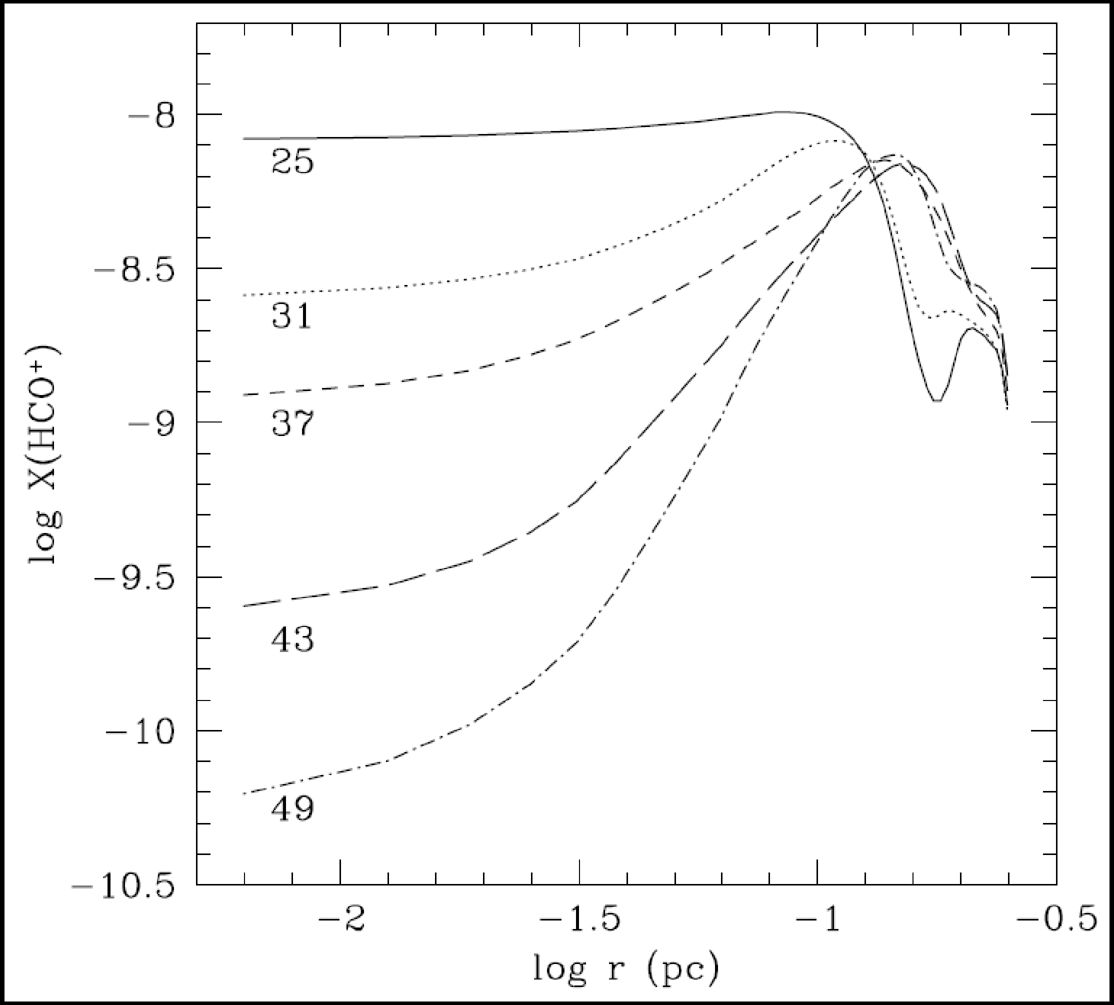
Sequence of Modeling for line profiles including both chemistry and dynamics



Lee, Bergin, & Evans (2004)

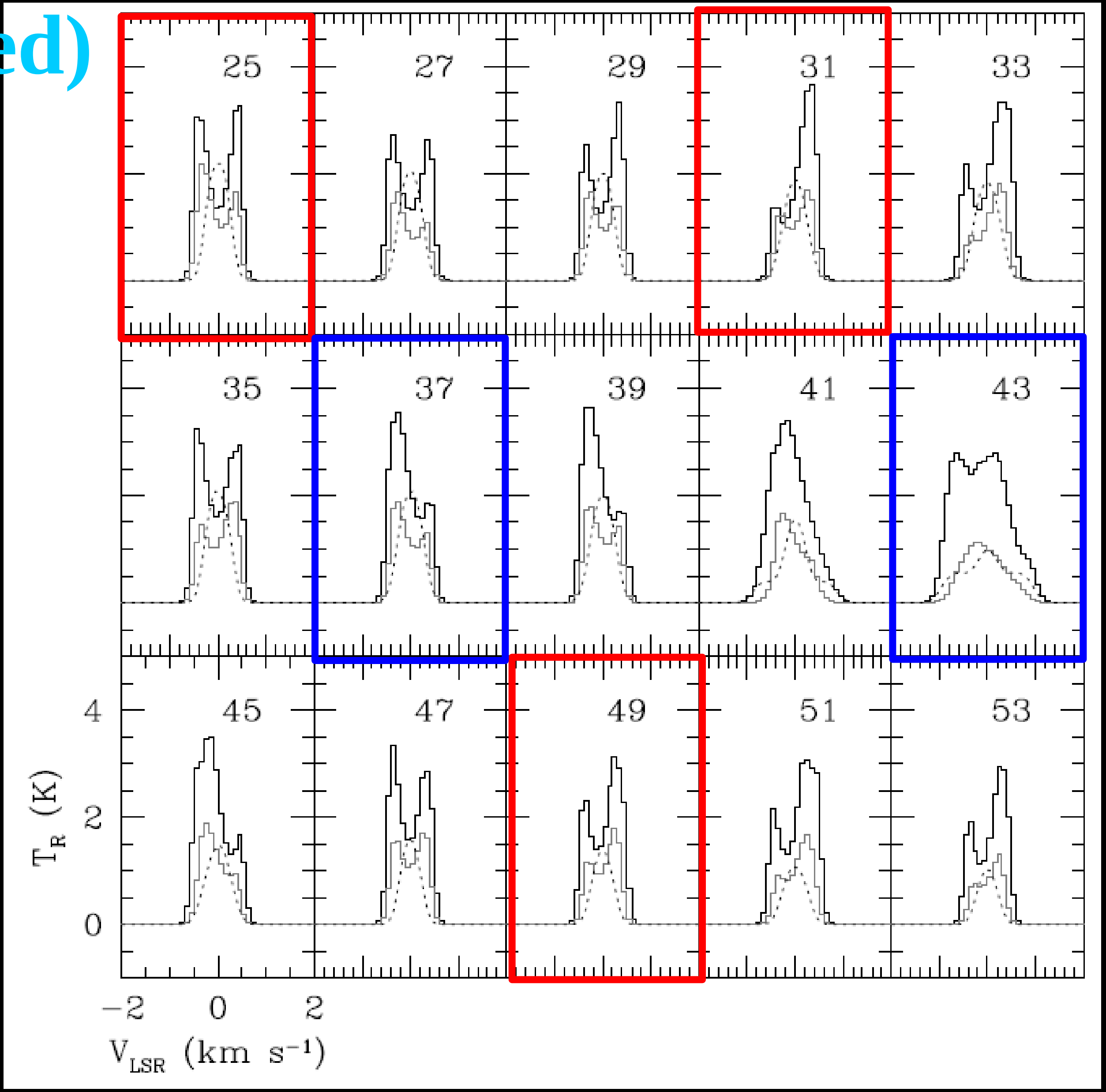
Evolution of HCO+ Abundance

- Evolutionary chemical model developed by Lee, Bergin, & Evans (2004)
- HCO+ is significant depleted as the density grows because CO becomes frozen-out onto grain surfaces.
- The abundance drop at the core boundary is due to the dissociative recombination of HCO+ with electrons.
- The HCO+ abundance has its peak at around 0.1pc.



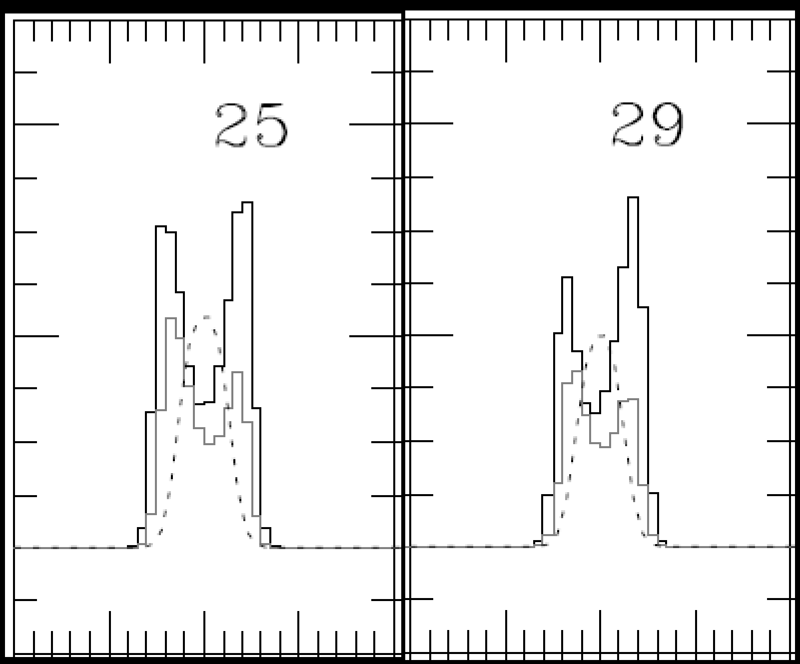
HCO^+ 3-2 (black), 4-3 (gray), $C^{18}O$ 3-2 (dotted)

- Monte-Carlo method (Choi et al. 1995)
- Distance to the model core: 250pc
- Beam size: 30 arcsec
- Two digit in each panel is time in units of 40,000 years
- As time goes on, the $C^{18}O$ line becomes weaker due to the depletion of CO.
- The line asymmetry is determined by a region where the abundance and velocity become large.

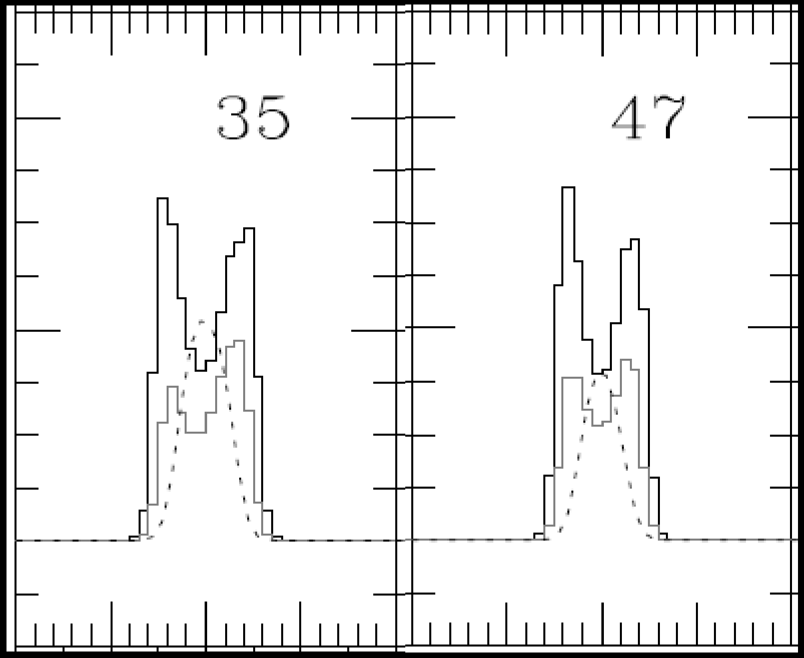


Change of asymmetry in HCO$^+$ 3-2 (black), 4-3 (gray)

Blue peak (3-2) to red peak (4-3)



red peak (3-2) to blue peak (4-3)



Conclusions

- Star (Core) formation rate per free-fall time in a turbulent molecular cloud was enhanced significantly by self-gravity.
- Molecular line profiles are affected by the coupled velocity and abundance structures in the outer regions of a core. The asymmetry of a core in turbulent environment easily changes from blue to red, and vice versa.