2006年2月21日　銀河系研究会@NAOJ

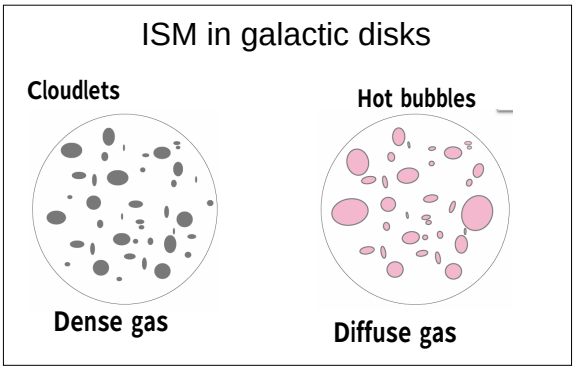
銀河円盤ガス構造の統計的性質

和田 桂一
国立天文台理論研究部

星形成領域を含むような星間ガスの大局構造の基本的性質は？

大局的星形成率 (e.g. Schmidt**則)は何で決まっているのか？**

実験的に調べてみた。



Universal? PDF of the ISM in galaxies

Log-Normal part: Highly inhomogeneous.
Higher density gases occupy smaller volumes.
Structures of dense gases are not independent of lower density gases.

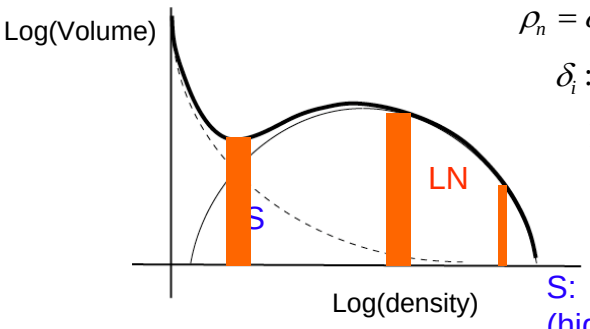
$$\rho_i = \delta_{i-1}\rho_{i-1}$$

$$\rho_n = \delta_n\delta_{n-1}...\delta_0\rho_0$$

δ_i :independent events

$$\ln(\rho_n) \to N(\mu, \sigma^2) \quad n \to \infty$$

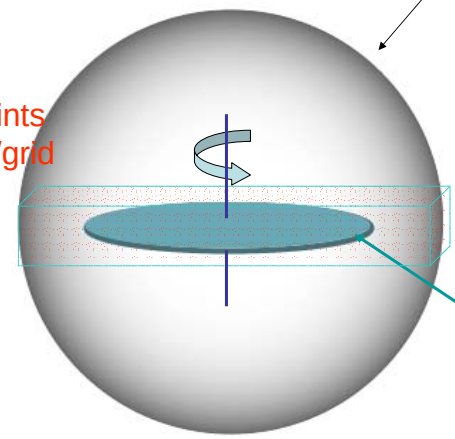
Central limit theorem



S: Smoothed part
(high-z gas dominated)

Globally stable disk → PDF does not evolve

3-D Hydrodynamics of a gas disk in a spherical galactic potential



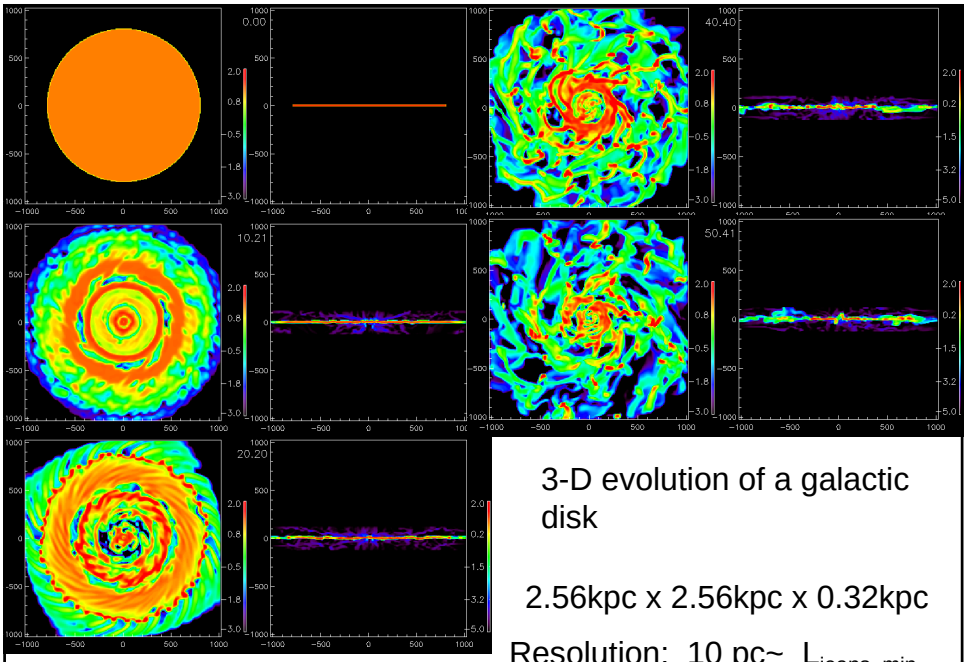
Evolution/Structure of a galactic gas disk -- 3-D Hydrodynamic Modeling --

Initial conditions and input physics:

- Rotationally supported, uniform disk in a fixed spherical potential (bulge + supermassive BH)
- Self-gravity of the gas
- A cooling function ($10<T<10^8$ K) is assumed.
- Heating sources: uniform UV
  - No Stellar energy feedback

Methods: AUSM w/ uniform grid+ Poisson eq. Solver(FFT)
CPU time: ~ 10-200 hours/run
on Fujitsu VPP5000 32 PEs (0.3 TF) in NAOJ

Wada & Norman (2001,2003), Wada (2001), Wada, Meurer, Norman(2002)

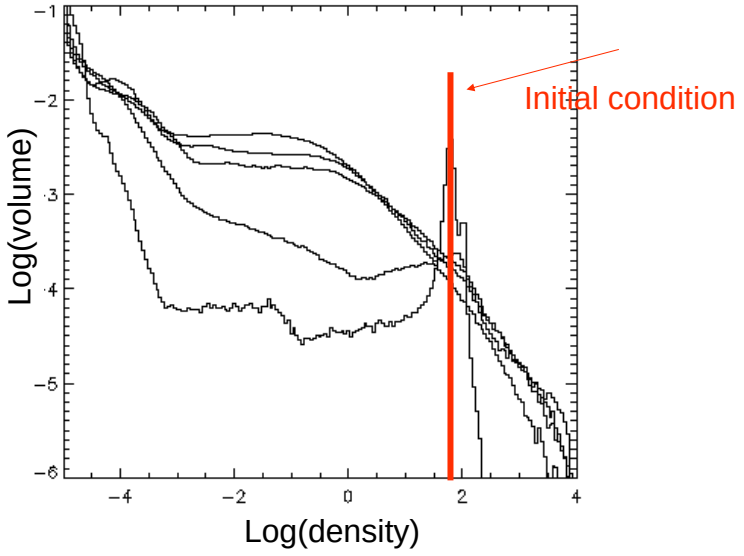


3-D evolution of a galactic disk

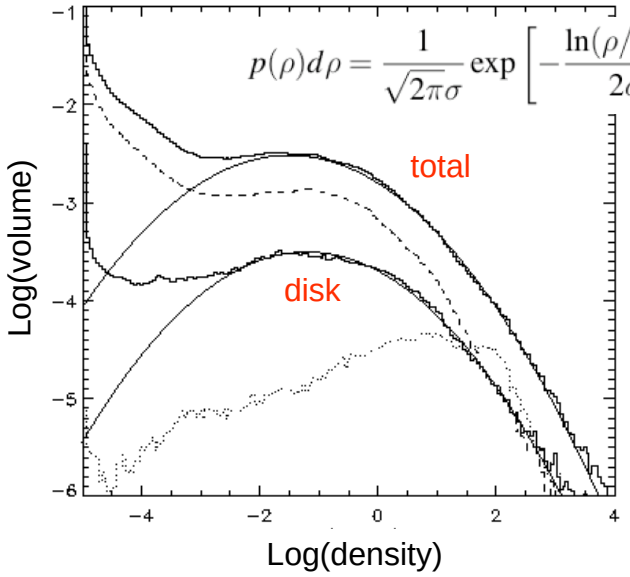
2.56kpc x 2.56kpc x 0.32kpc

Resolution: 10 pc~ $L_{jeans,\ min}$

Evolution of PDF in 3-D galactic disk



Volume-weighted density PDF in a steady-state



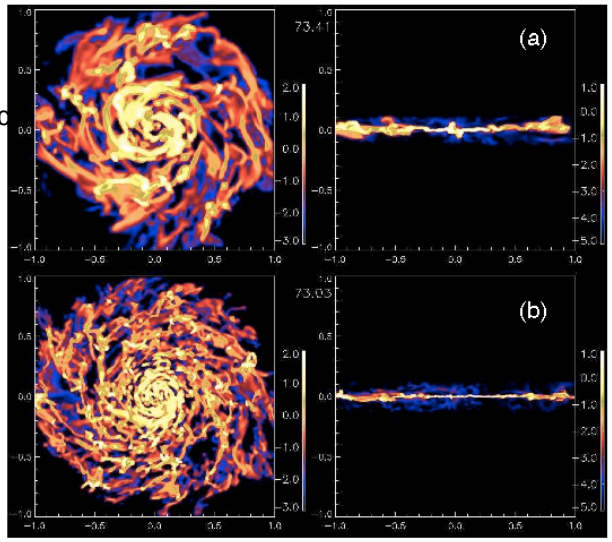
Resolution dependence

256x256x32

Δ =10pc

512x512x64

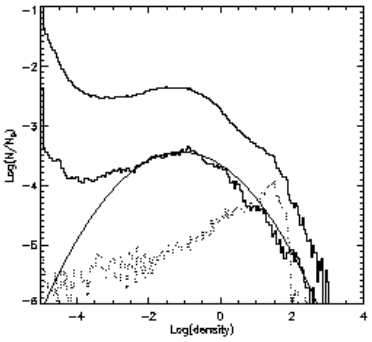
Δ =5pc



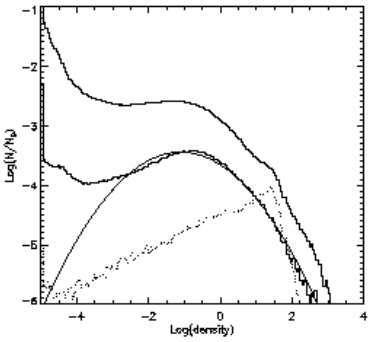
T_{min} ~ 140 K (density/10M_{sun} pc^{-3})(**Δ**/10pc)^2

Density PDF in a 3-D galactic disk

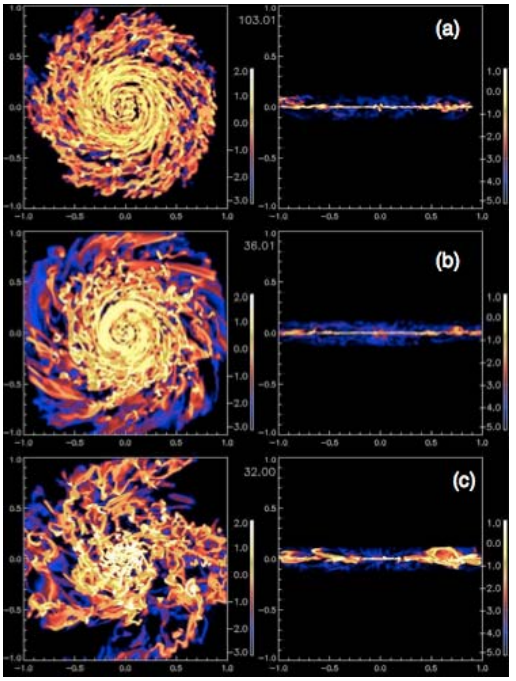
resolution =10pc



resolution =5pc



Dependence of total gas mass

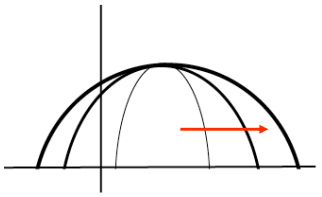


Less massive

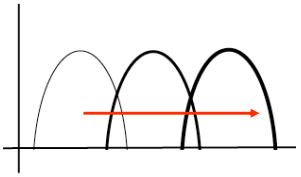
massive

How is the dispersion in LN-PDF determined?

- Suppose LN-PDF, PDF could respond for increasing total gas mass as follows:



(1) Reference density is const., & dispersion increases.

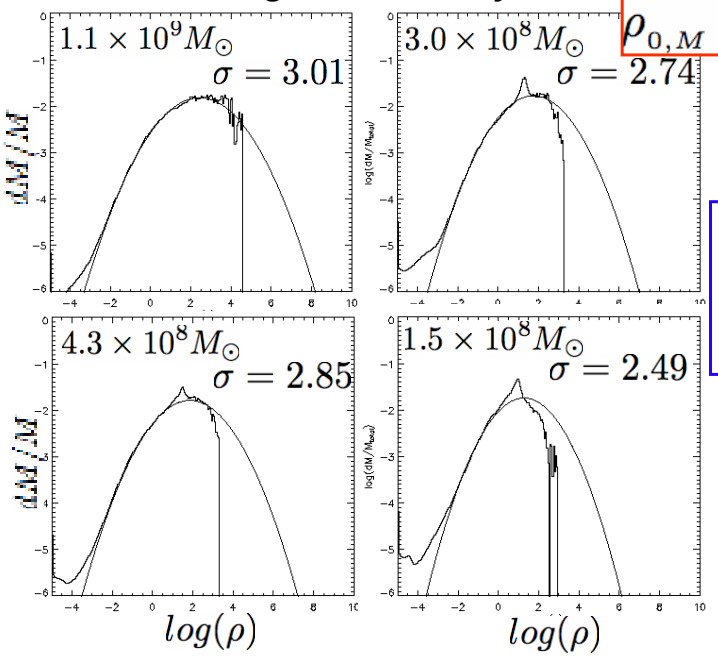


(2) Dispersion is the same, & Reference density increases.

Mass-weighted density PDF

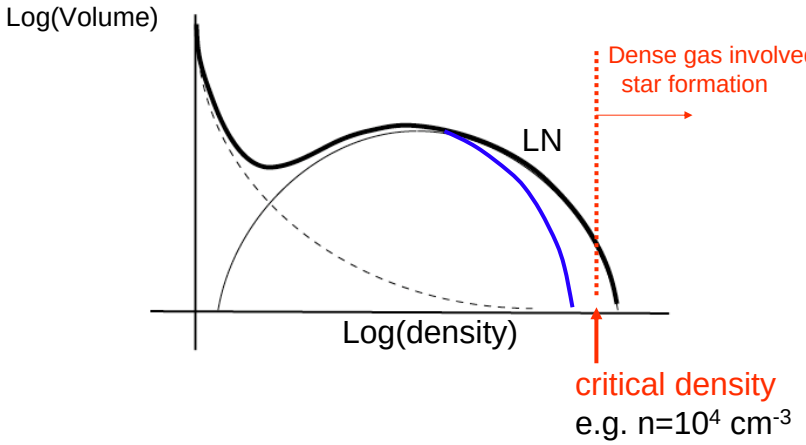
For LN-PDF

$$\rho_{0,M} = \rho_{0,V} e^{\sigma^2}$$



In more massive disks, the LN-dispersion is larger.

PDF & star formation



Whether the system is stable/unstable is independent of the local star formation.

SFR in the ISM characterized by LN-PDF

$$SFR = \epsilon_c (G\rho_c)^{1/2} f_c M_g(\sigma)$$

efficiency

Gas mass involving LN pdf

$$p(\rho)d\rho = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{\ln(\rho/\langle\rho\rangle)^2}{2\sigma^2}\right] d\ln\rho,$$

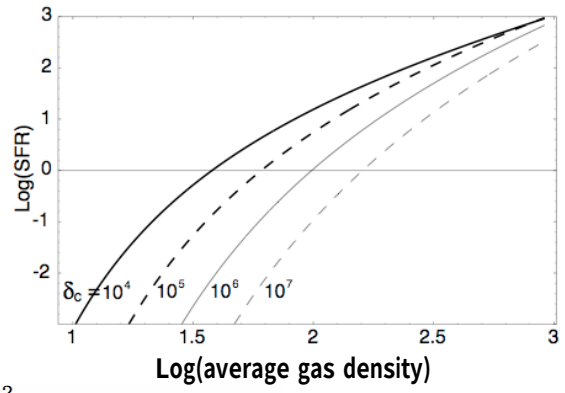
Fraction of gas denser than a critical density:

$$f_c(\delta_c) = \frac{\int_{\ln\delta_c}^{\infty} \delta \exp\left[-\frac{(\ln\delta)^2}{2\sigma^2}\right] d(\ln\delta)}{\int_{-\infty}^{\infty} \delta \exp\left[-\frac{(\ln\delta)^2}{2\sigma^2}\right] d(\ln\delta)}, \qquad \delta_c \equiv \rho_c/\rho_0$$

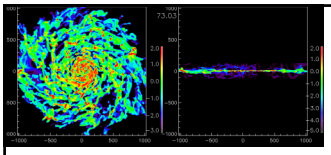
$$= \frac{1}{2}[1 - \mathrm{Erf}[z(\delta_c)]] \qquad z(\delta_c) \equiv \frac{\ln\delta_c - \sigma^2/2}{\sqrt{2}\sigma}$$

SFR as a function of average gas density based on the LN-pdf model

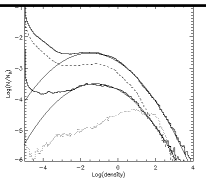
- Higher SFR for lower critical density
- For higher critical density, SF is more sensitive for increasing gas mass



$$\rho/\rho_i = \xi e^{\frac{\sigma^2}{2}}(1+Erf[\sigma/\sqrt{2}])$$



まとめと課題



- kpcスケールでのISM密度の統計的構造
  - Log-Normal PDFで記述できる (物理の詳細によらない。非線形であればよい。 例 SNe)
    - 高密度分子ガスの統計構造は低密度ガスと関係している
    - 大局的星形成率はISMの全体構造とcritical densityが決めている
    - 星形成と銀河円盤の安定性はあまり関係ない
  - Dispersion ⇒ total gas massの関数

- Universal？ Robust？
  - 銀河形成時の星形成率の決定
  - Schmidt則に代わりうるかもしれない (e.g. 銀河形成シミュレーション、sub-grid physics)
- Starburst mode は存在するのか？ 観測的検証