SF@50
5 -10 July, 2009, Siena, Italy

Relations between the Global SFR and Intrinsic Structures of the ISM in Galactic Disks

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1) Euler grid modeling galactic disks
2) SPH modeling galactic disks
3) Euler grid modeling a molecular disk around an SMBH

Q1: What determines the global SFR?

A_1: Gravitational, thermal, magneto-rotational or hydrodynamic instabilities in a gas disk

A_2: Turbulence in molecular clouds

A_3: Collisions between molecular clouds

A_4: Molecular fraction in dense ISM

A_5: Galactic rotation

A_6: Galactic spiral

A_7: H_2 chemistrory, FUV

....

Q2: Then, which is the most important?

A: All. So we need a 5-day workshop!

Today'talk = A simple theoretical picture on global SFR

Combination of these processes produces a mess in a galactic disk ==> a robust statistical feature in the ISM ==> KS-like SF law

Numerical Experiment of global evolution of galactic disks using a hydrodynamic code:

HD.AUSM.MUSCL.Cartesian.Uniform.Convolution.FFT.radiative_cool.Zsun.photoelectric_heating.SN_heat.spherical_pot.SMBH.STAR.Xray.Condaction.H2

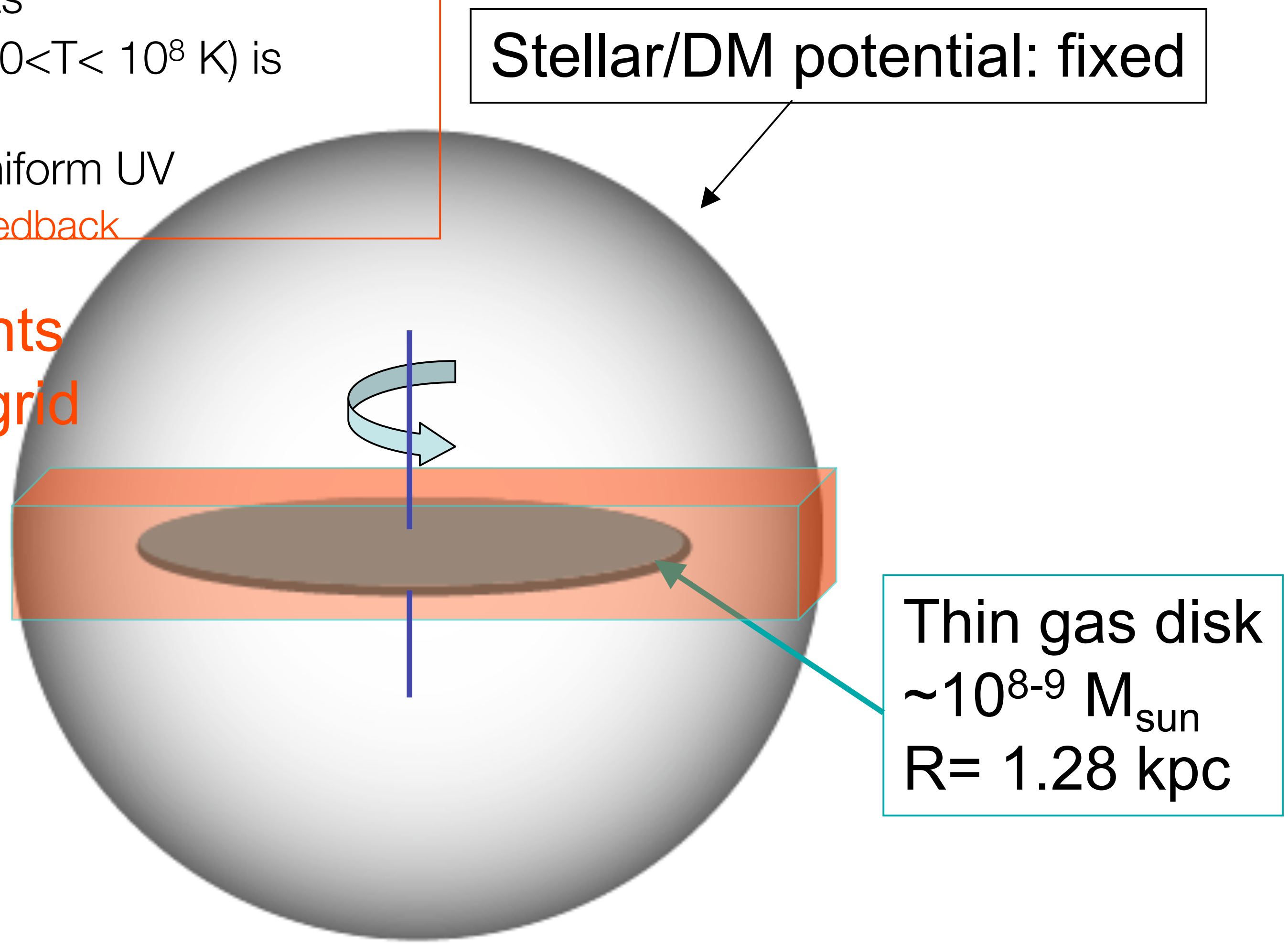
e.g.

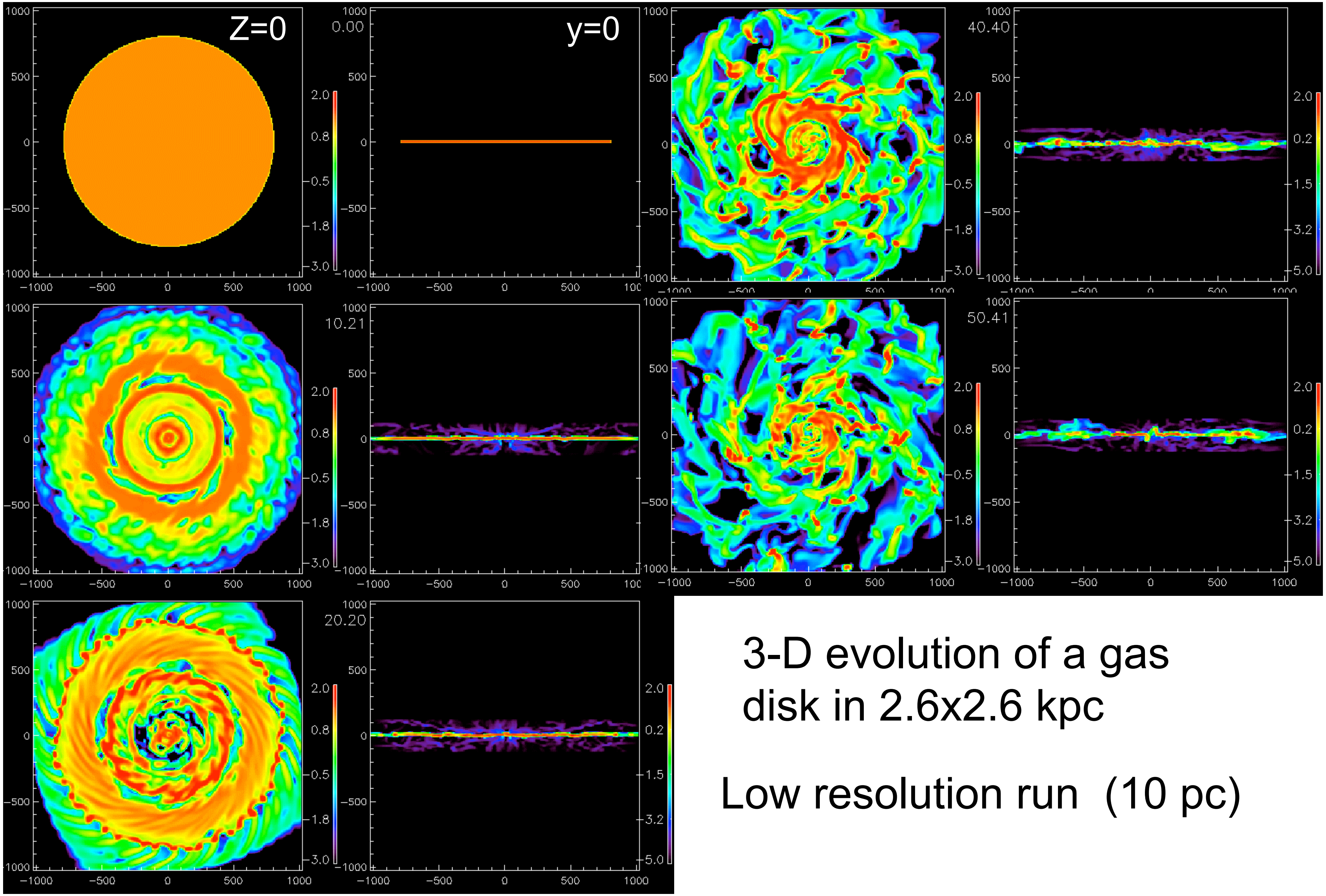
tracking stellar particle: HD.*.STAR
H2 formation/dissiociation: HD.*.H2
Spiral potential: HD.*.spiral_pot
Xray heating: HD.*.Xray

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

- Self-gravity of the gas
- A cooling function ($10 < T < 10^8$ K) is assumed (solar)
- Heating sources: uniform UV
  - No SNe energy feedback

512^2x64 grid points
Resolution: 5pc/grid
(also 10pc/grid)



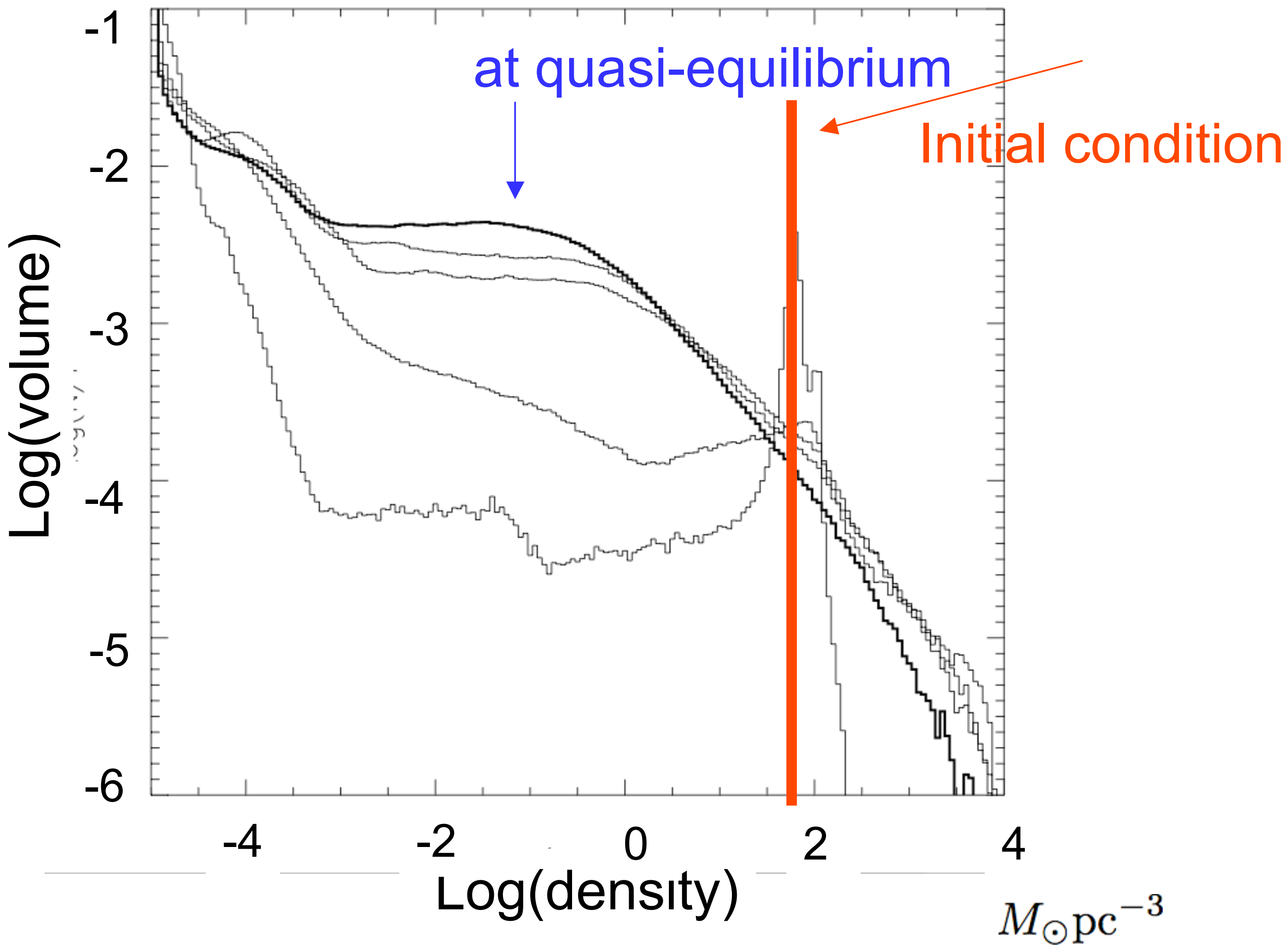


3-D evolution of a gas disk in 2.6x2.6 kpc

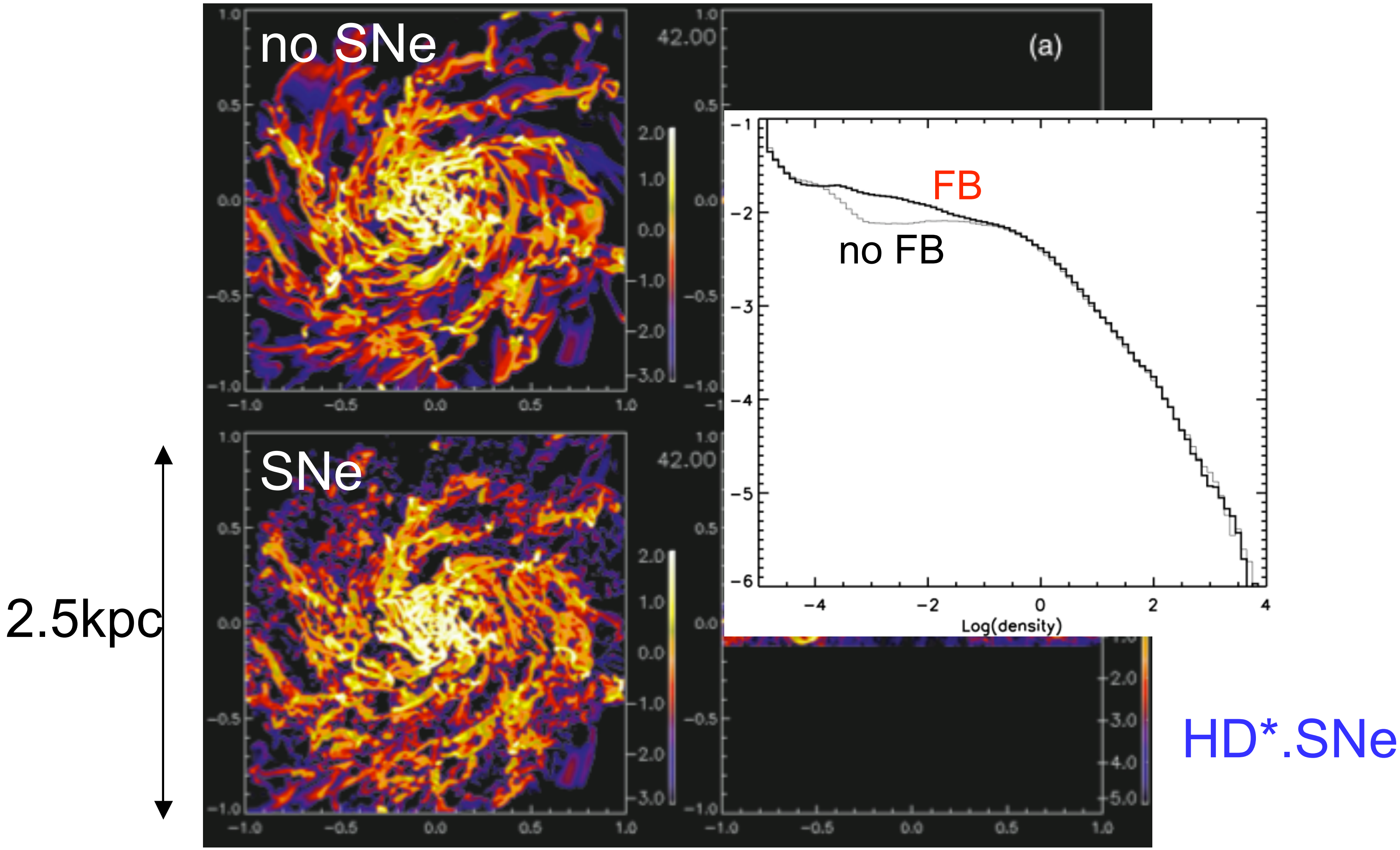
Low resolution run (10 pc)

Evolution of density PDF in the unstable disk

High-density tail and low density part are coupled, and the final PDF shows a smooth distribution.



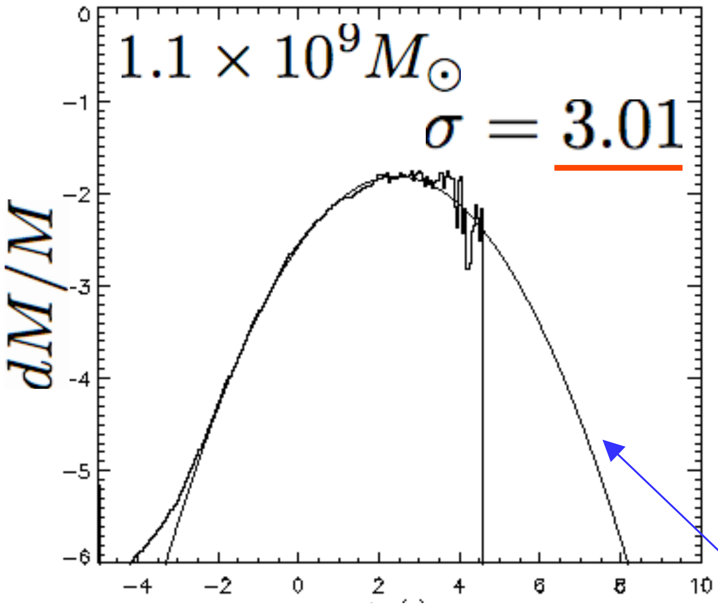
The density PDF is robust for energy feedback from SNe

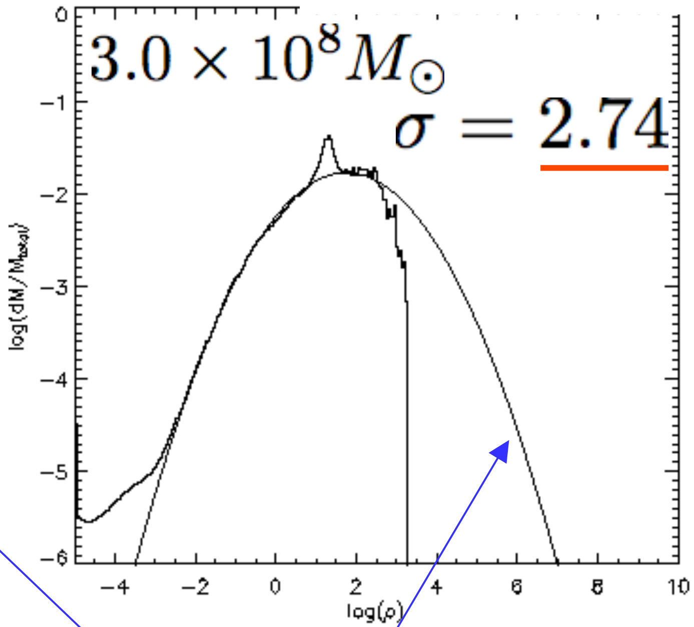


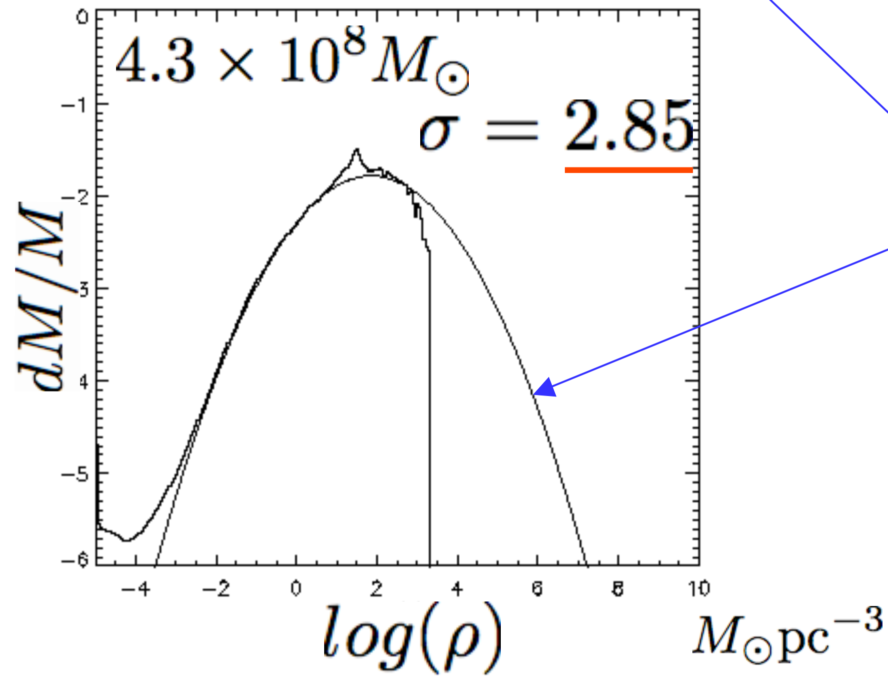
Positions of energy input are randomly selected.
SN rate= 1.5×10^{-5} yr^{-1} kpc^{-2}

Mass-weighted density PDF

$$f(\rho)\,d\rho = \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{\ln(\rho/\rho_0)^2}{2\sigma^2}\right]d\ln\rho$$







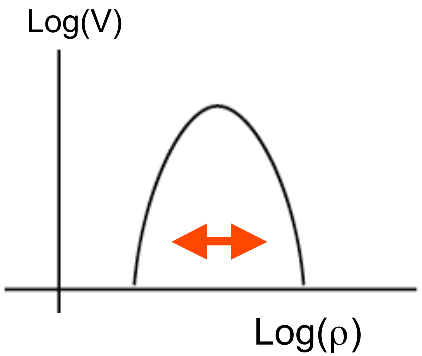
In more massive disks, the LN-dispersion is larger.

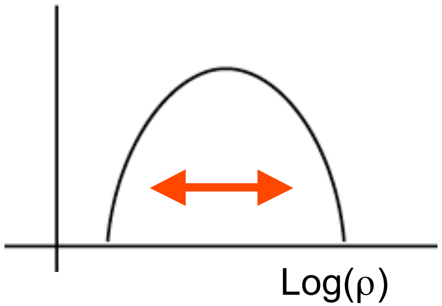
For LN-PDF

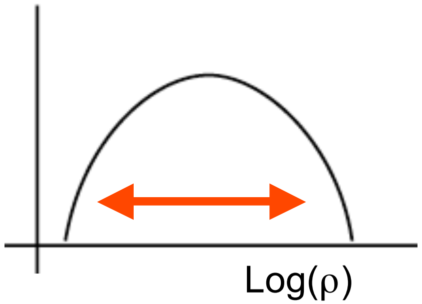
$$\sigma^2 = \frac{1}{2}\ln(\langle\rho\rangle_M/\rho_0)$$

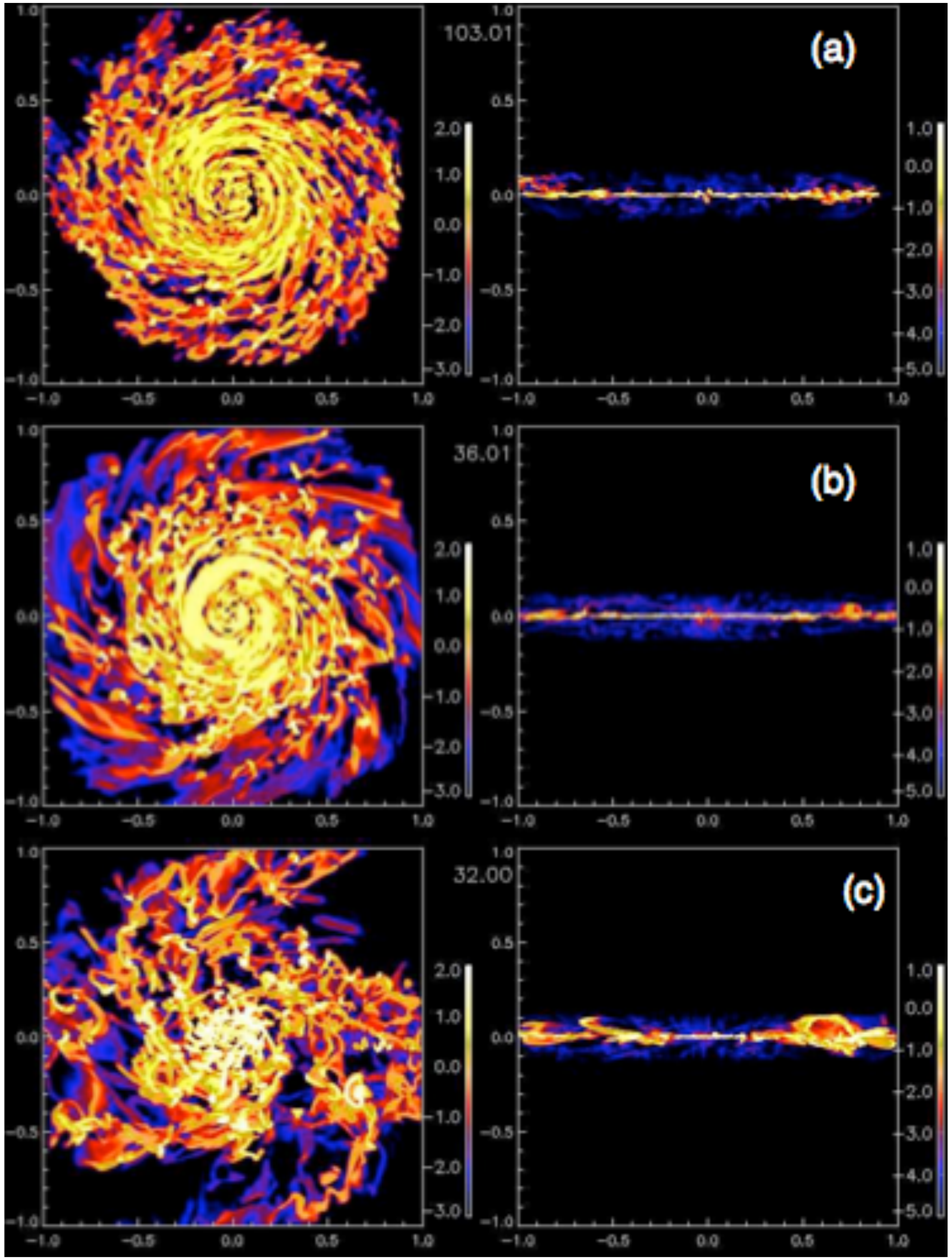
ρ_0 is nearly constant.

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









M_{gas} =

$3.0 \times 10^8 M_\odot$

Less massive

$4.3 \times 10^8 M_\odot$

$1.1 \times 10^9 M_\odot$

massive

$$\langle \rho \rangle_V = \rho_0 e^{\sigma^2/2}$$

Larger dispersion in more massive system

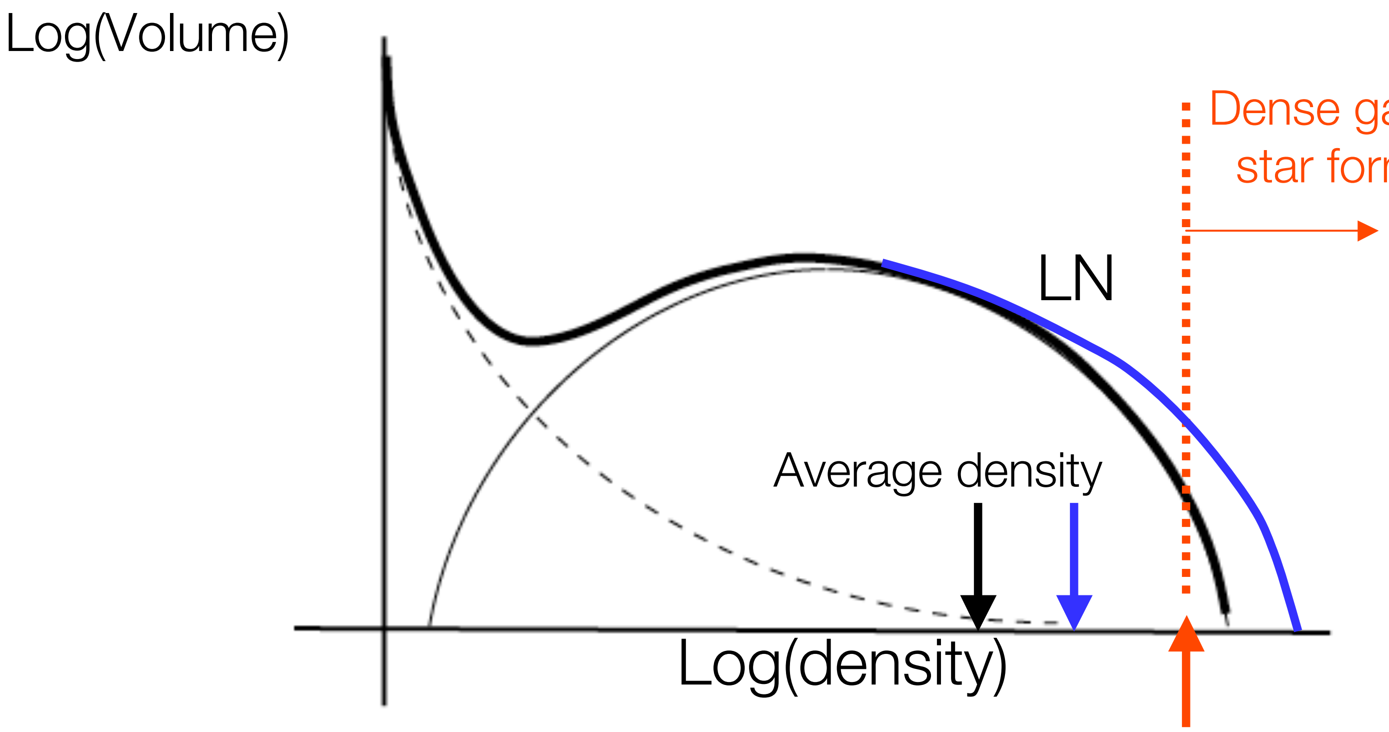
star formation model based on LN-PDF

Elmegreen (2002), KW & Norman (2007)

Average density ↑ ⇔ dispersion of LN ↑

cf. Krumholtz& McKee 05 for molecular clouds

⇒fraction of high density clumps ↑ ⇒ SFR ↑



threshold density for local SF

e.g. n=$10^{3\text{-}5}$ cm^{-3}

$$\langle\rho\rangle_V = \rho_0 e^{\sigma^2/2}$$

SFR is scaled to gas density averaged on a kpc-scale

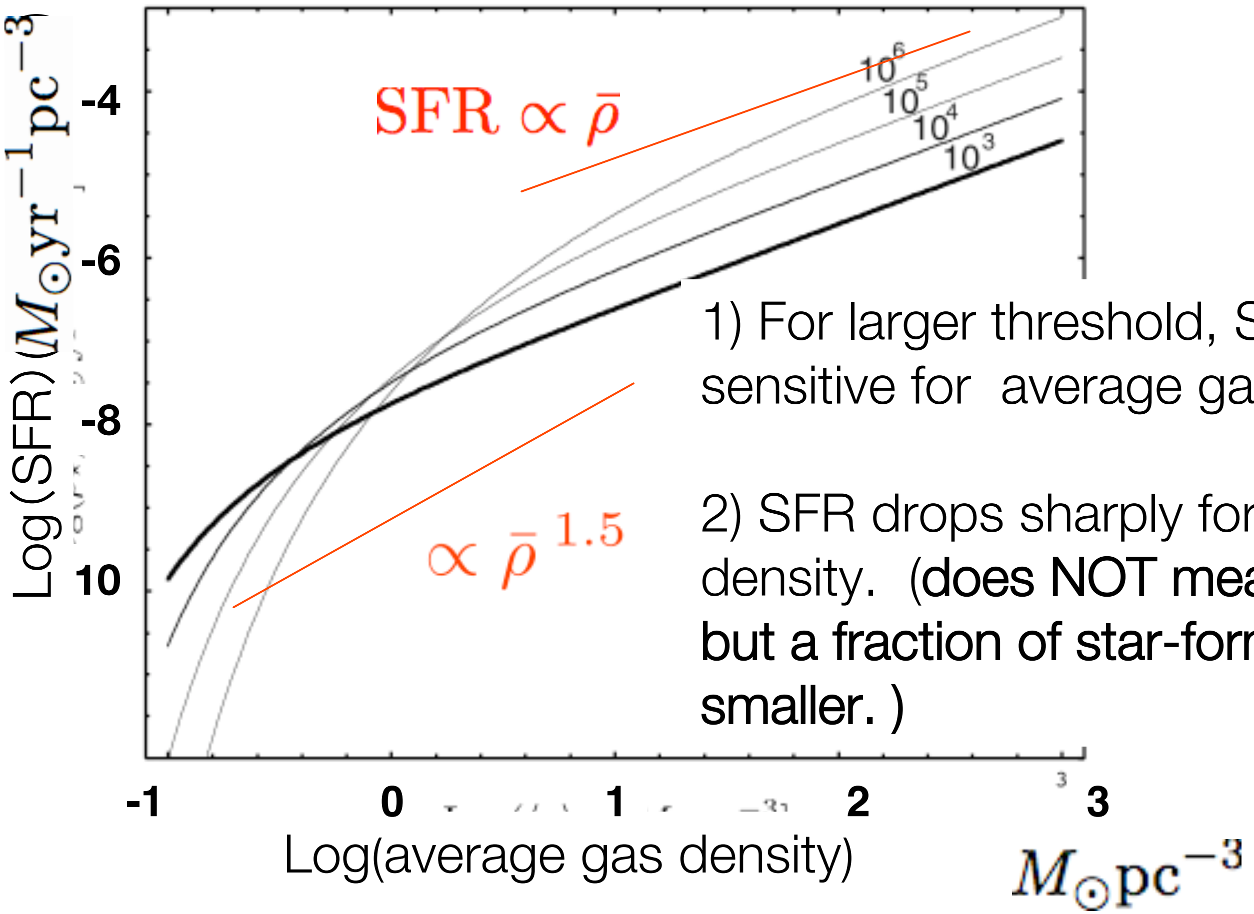
KW&Norman07

If stars are formed in a free fall time above the threshold density,

$$\dot{\rho}_\star = \epsilon_c (G\delta_c)^{1/2} f_c \rho_0^{3/2} e^{\sigma^2/2}$$

Threshold density=$10^6, 10^5, 10^4, 10^3$ cm^{-3}

efficiency



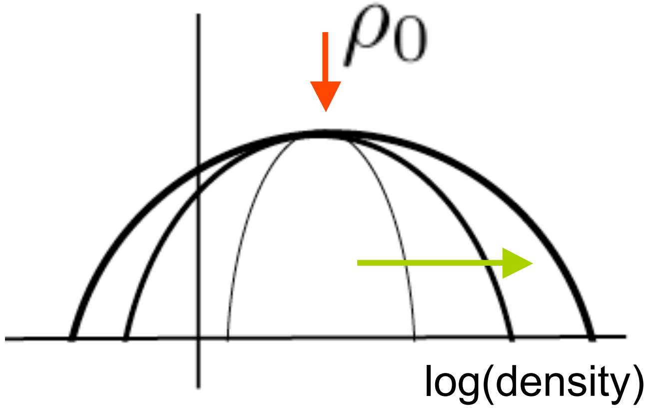
1) For larger threshold, SFR is more sensitive for average gas density.

2) SFR drops sharply for lower density. (**does NOT mean Q >1, but a fraction of star-forming gas is smaller.**)

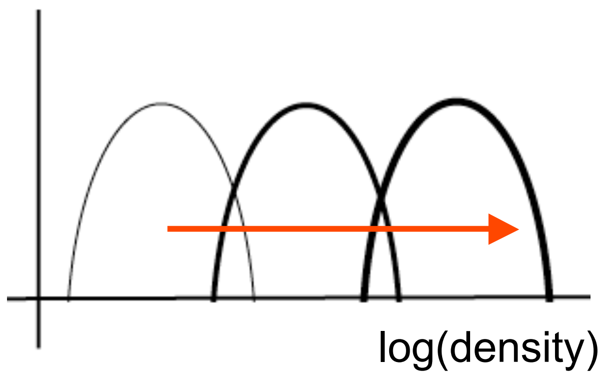
How does PDF change depending on total gas mass (average density)?

- Suppose the density distribution is represented by LN-PDF, the PDF responds to increasing the total gas mass by two ways:

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



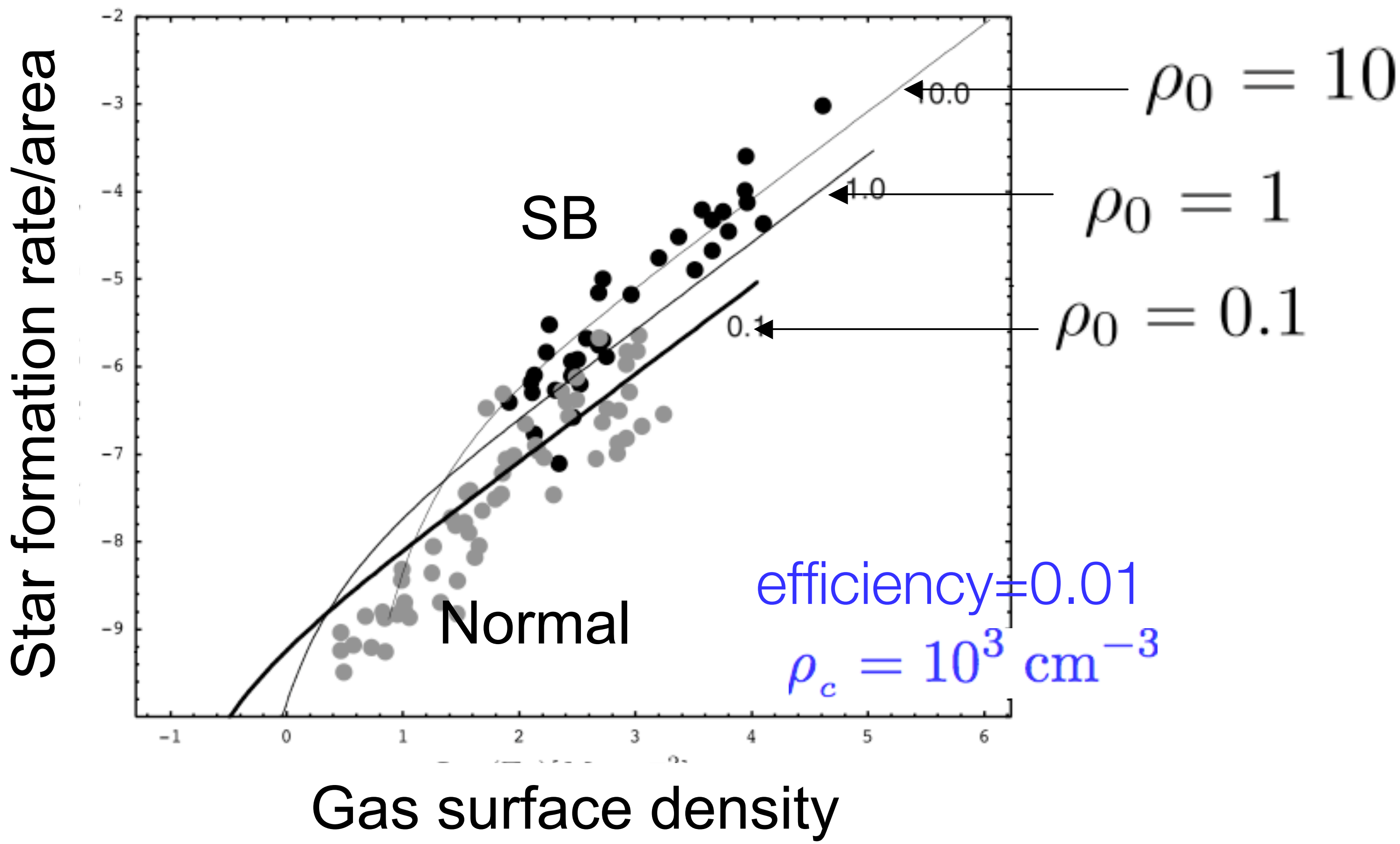
(2) Dispersion is constant, & Characteristic density increases.



Parameter to fit observed SFR: $\rho_0 \quad \epsilon_c \quad \rho_c$

Comparison with observed SFR

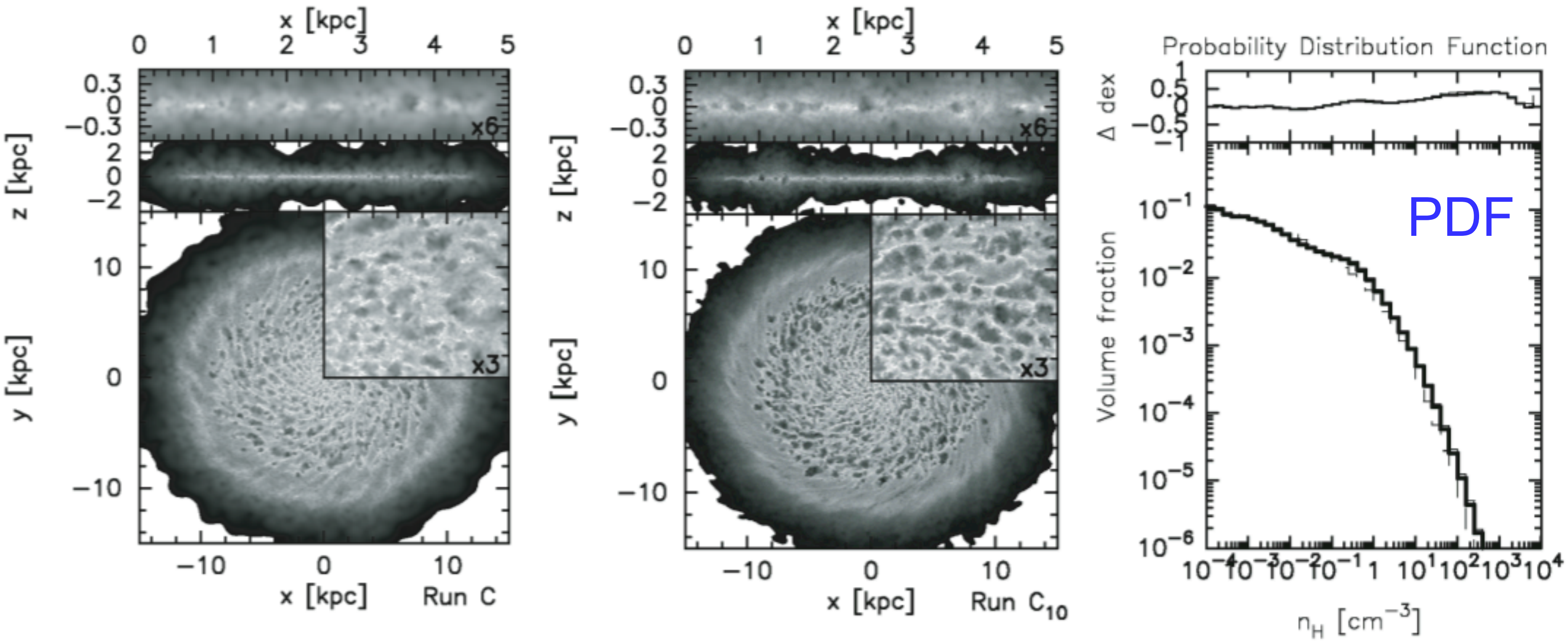
In starburst galaxies, the characteristic density (ρ_0) should be larger, for a given efficiency and threshold density of local star formation.



Observed data: Komugi + (2005) based on CO survey in Nobeyama

N-body/SPH simulations (*ASURA*)

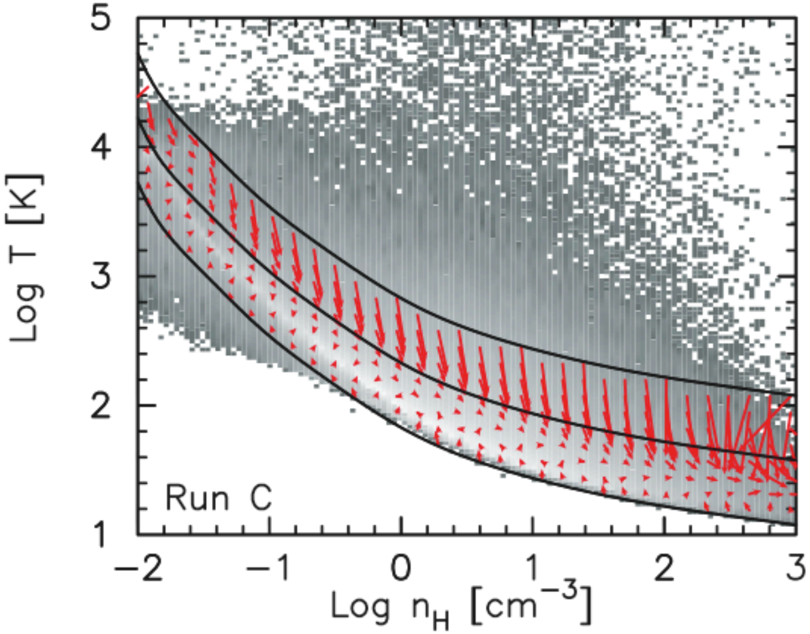
Saitoh et al. (2008) PASJ 60, 667

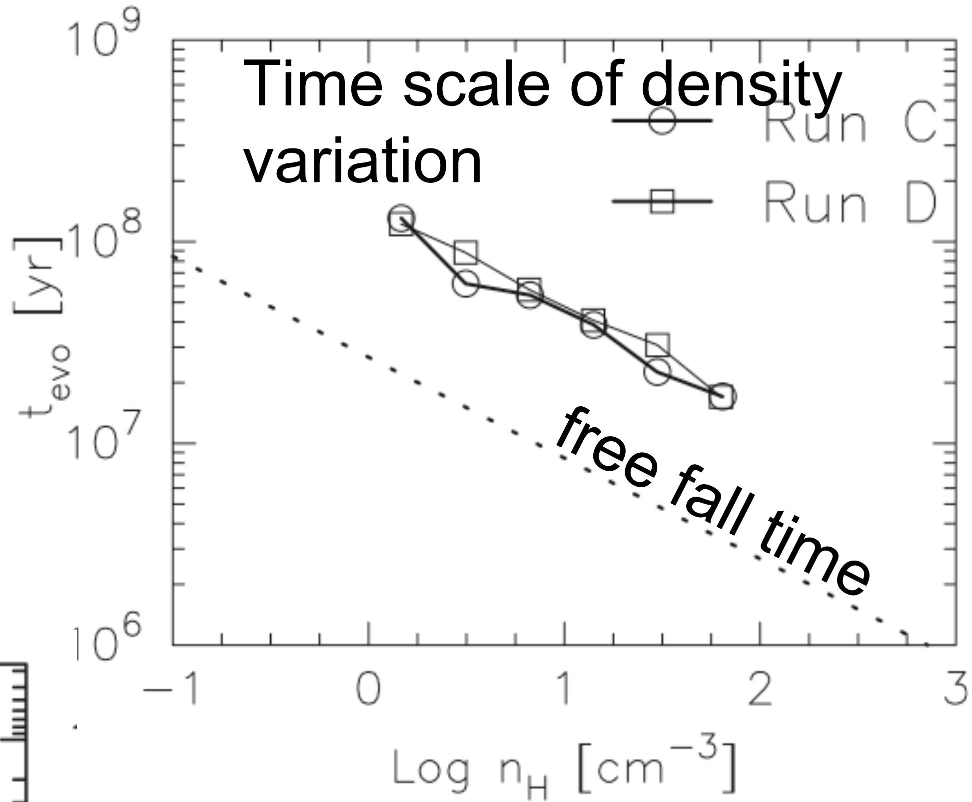


$N_{SPH}=10^6$ $N_{SPH}=10^7$

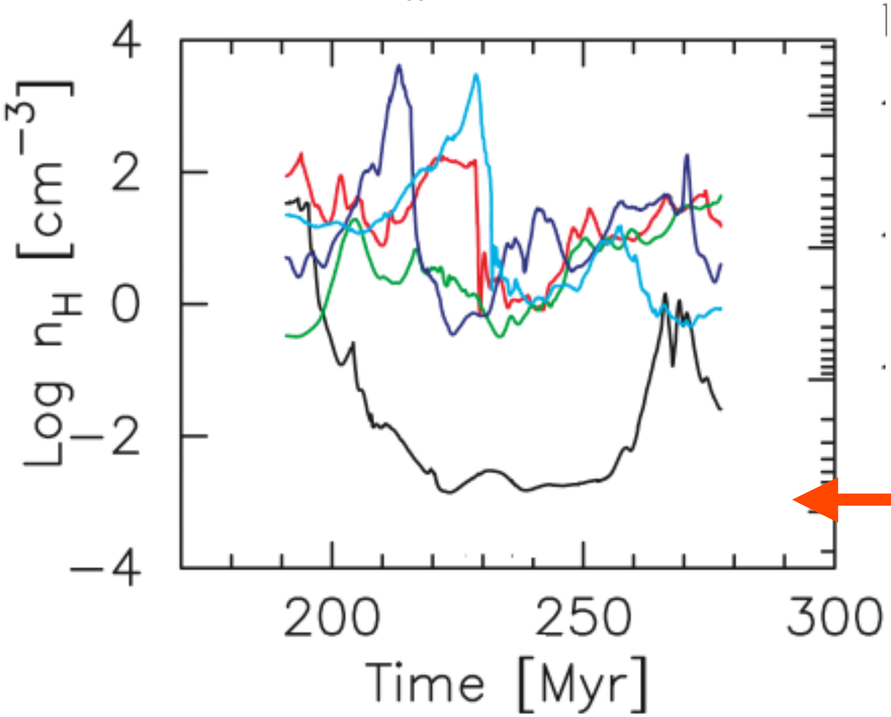
Density structures converge

Mass supply toward high density region is slow!





Net evolution of density is ~ 5 x slower than free fall time on average



"Random walk" in density

Density and temperature distribution around a SMBH

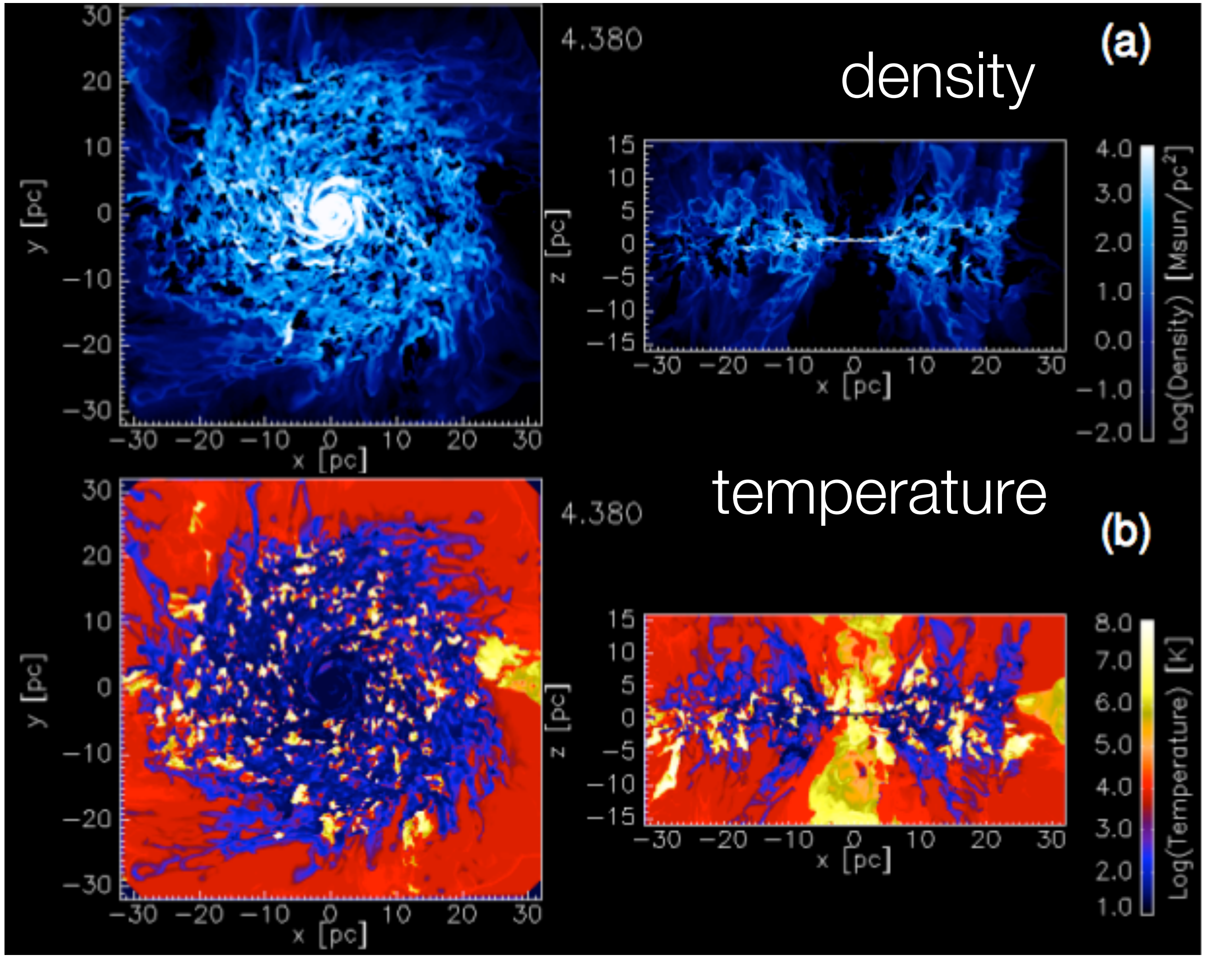
$M_{BH} = 1.3x10^{7}\ M_{sun}$
$M_{gas} = 6x10^{6}\ M_{sun}$

Wada,Papadopoulos, Spaans (2009) arXiv:0906.5444

HD*.H2.SMBH.SNe

Resolution: 0.125 pc

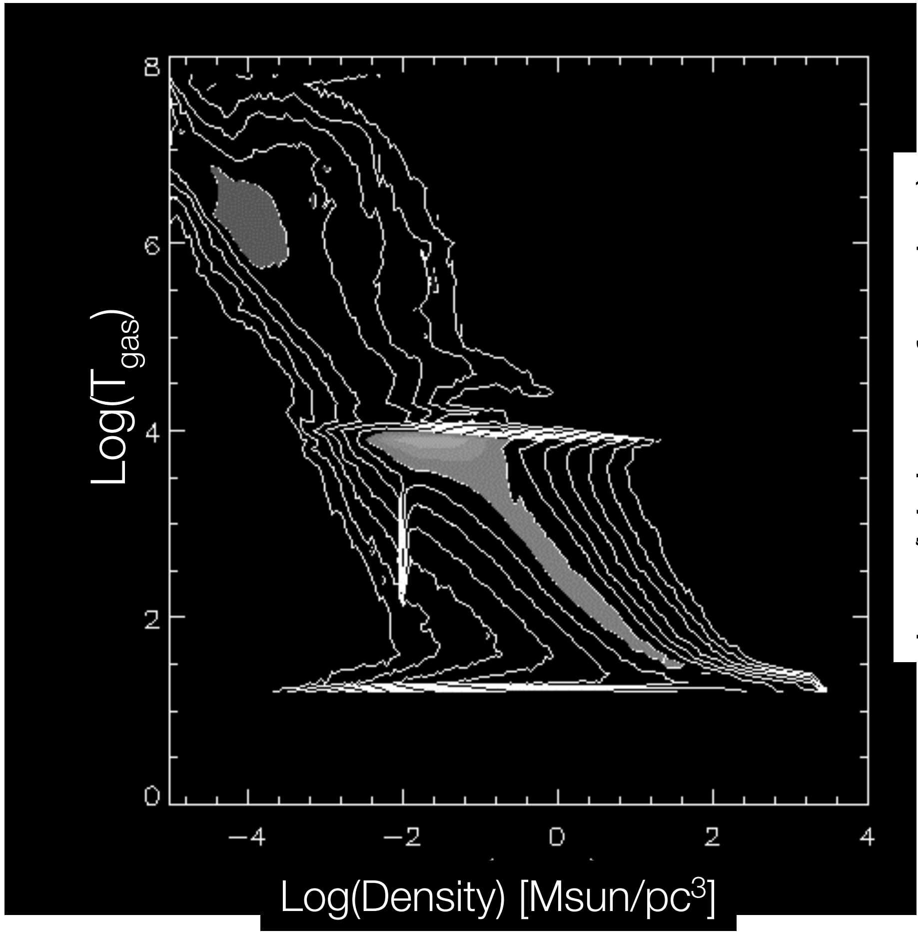
64 pc

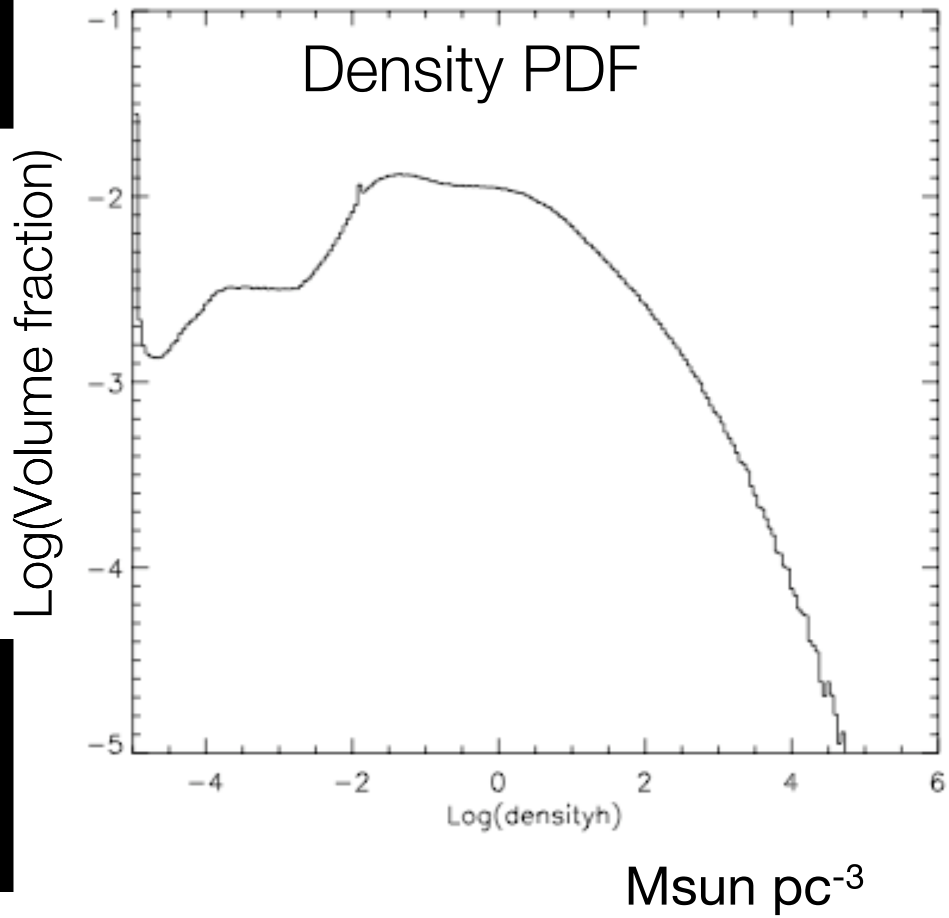


G_0 = 10

SN rate
= $5x10^{-5}$/yr

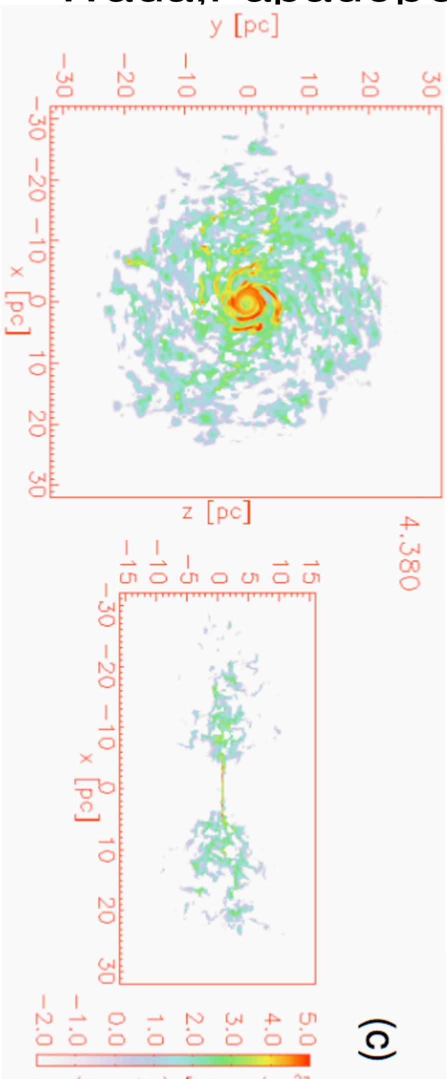
Phase-diagram and PDF in a galactic central region



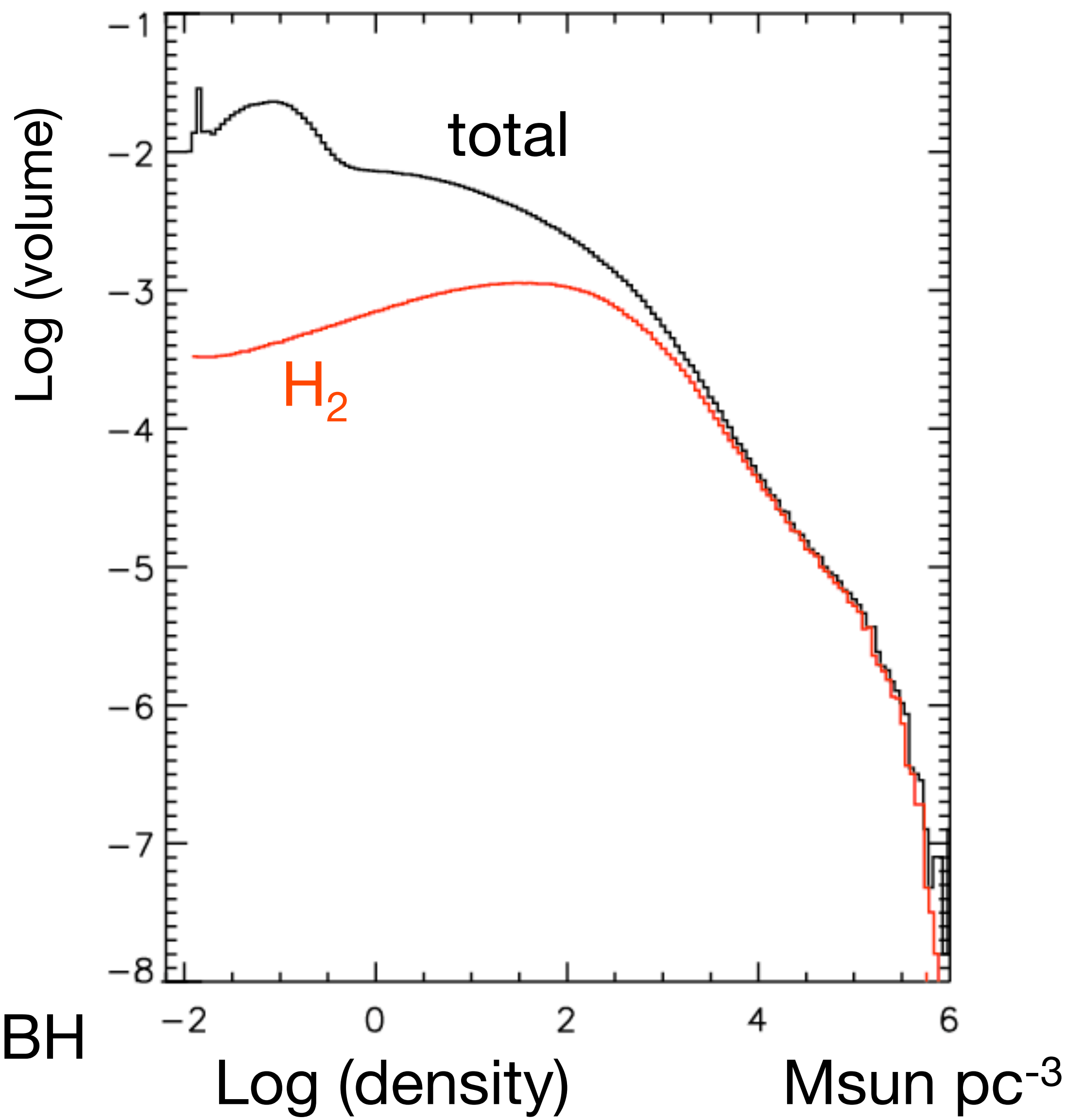


Density&H_2 PDF in a galactic central region

Wada, Papadopoulos, Spaans (2009) arXiv:0906.5444



H_2 “torus” around a SMBH



summary

- The inhomogeneous ISM in globally stable disks can be characterized by a Log-Normal like density PDF
  - Global SFR is controlled by a mass fraction in high density regions, which is NOT independent of lower density regions.
  - Time-scale of global SF is not determined only by the free fall time of high density gas, but also by evolutional time scale toward high density regions.
  - Mass ‘flow’ is slow in a statistical sense due to diffusion-like evolution in a density space.
- Non-LN PDF or multi-component PDF would be also the case in realistic situations.