Nonlinear Instability of The Cold Cloud in a Two-Phase Interstellar Medium

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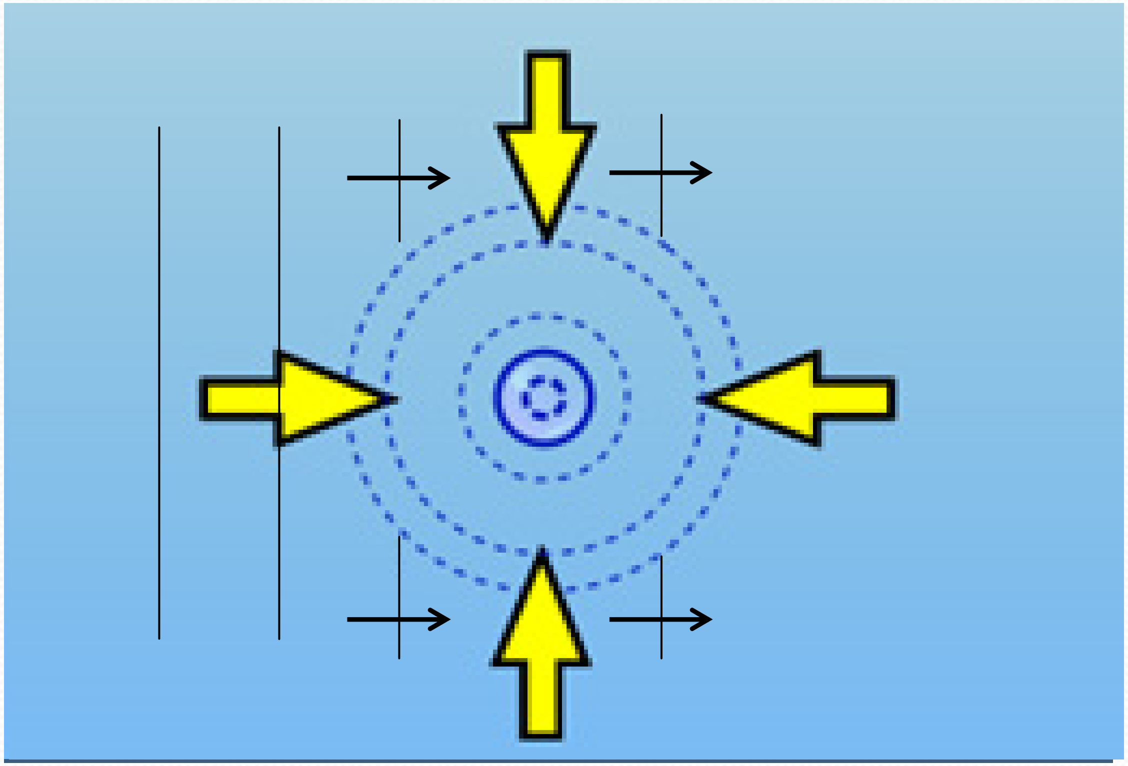
Outline

- Sonoluminescence
- Governing Equations
- Result
- Conclusions

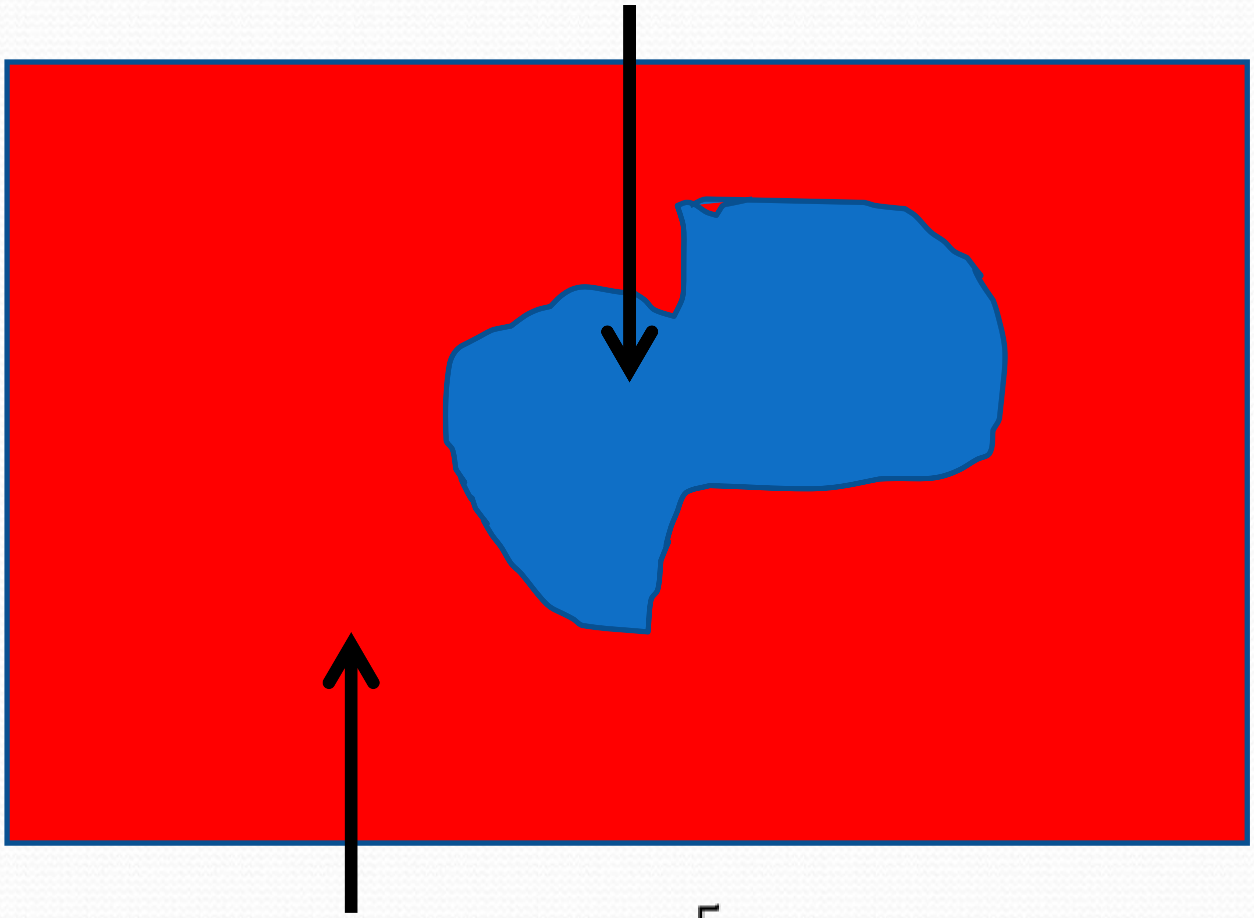
Sonoluminescence

- Soft air bubble is compressed by the resonant ultrasonic wave in a hard liquid.



Two-Phase Interstellar Medium

Cold molecular cloud: soft ($\gamma = 0.7$)



Hot gas: hard ($\gamma = \frac{5}{3}$)

For Example:

Cloud size ~ 100pc

Cloud Mass ~ 10^5 M_{sum}

Cloud temperature = 100K

Characteristic time ~ 10^7 yr

Hydrogen number density of the cloud ~ $10^2/cm^3$

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Governing Equations

$$\partial_t \rho + \nabla \cdot (\rho \boldsymbol{V}) = 0$$

$$\partial_t (\rho \boldsymbol{V}) + \nabla \cdot \left(\rho \boldsymbol{V} \otimes \boldsymbol{V} + P \underline{\boldsymbol{I}}\right) = -\rho \nabla \Phi$$

$$\partial_t E + \nabla \cdot \left((E + P)\boldsymbol{V}\right) = -\rho \boldsymbol{V} \cdot \nabla \Phi$$

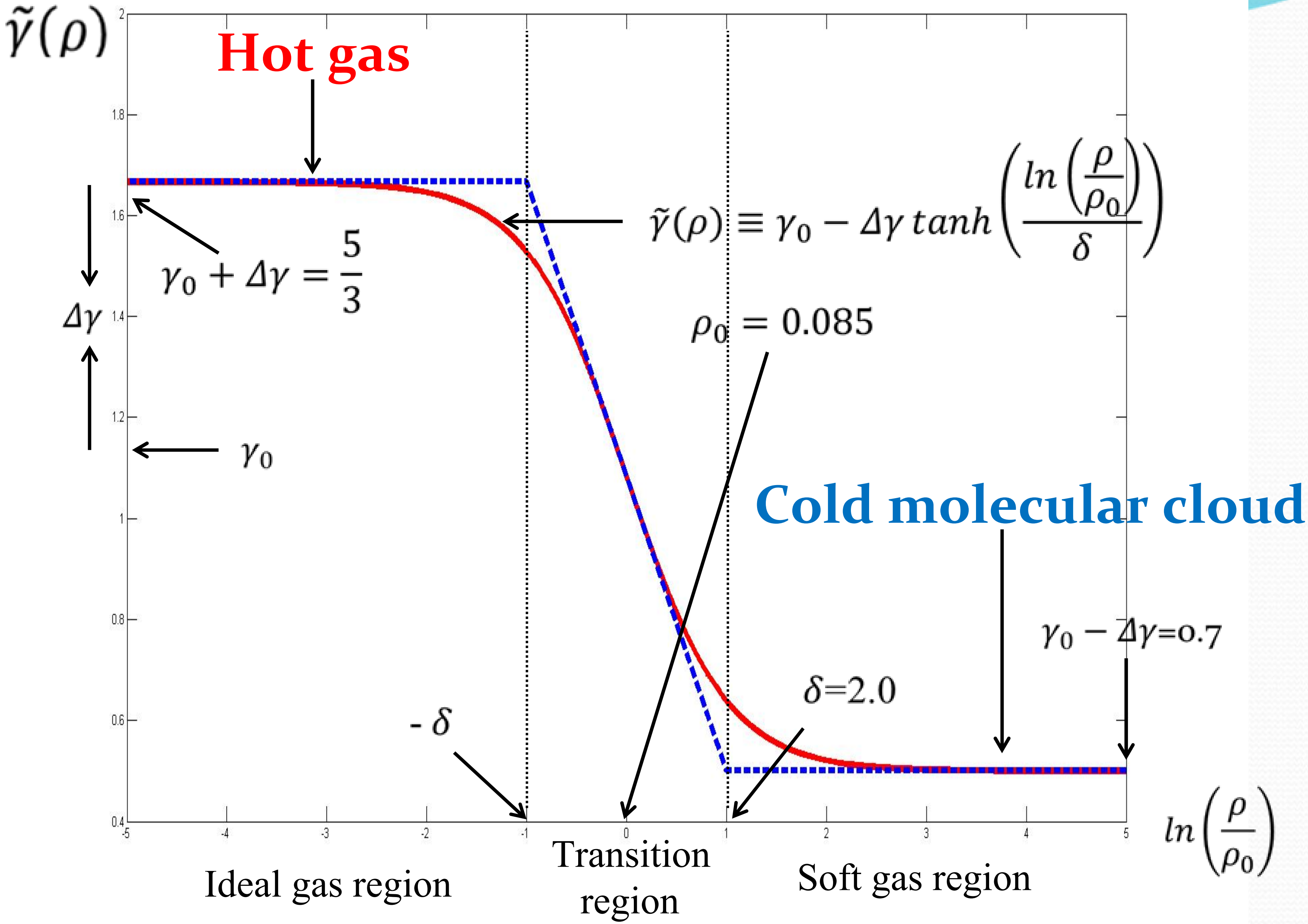
$$\nabla^2 \Phi = 4\pi G \rho$$

$$E = e + \frac{1}{2}\rho(\boldsymbol{V} \cdot \boldsymbol{V})$$

$$e = \rho \int_0^{\rho} [\frac{P(S,\rho')}{\rho'^2}]_S \, d\rho' \qquad ; P = a(S)(\frac{\rho}{\rho_0})^{\tilde{\gamma}(\rho)}$$

$$\tilde{\gamma}(\rho) \equiv \gamma_0 - \Delta\gamma \, tanh\left(\frac{ln\left(\frac{\rho}{\rho_0}\right)}{\delta}\right)$$

[for ideal gas: $P = a(S)(\frac{\rho}{\rho_0})^{\gamma}$]


$\tilde{\gamma}(\rho)$
Hot gas
$\tilde{\gamma}(\rho) \equiv \gamma_0 - \Delta\gamma \tanh\left(\frac{\ln\left(\frac{\rho}{\rho_0}\right)}{\delta}\right)$
$\gamma_0 + \Delta\gamma = \frac{5}{3}$
$\Delta\gamma$
$\rho_0 = 0.085$
γ_0
Cold molecular cloud
$\gamma_0 - \Delta\gamma$=0.7
δ=2.0
- δ
$\ln\left(\frac{\rho}{\rho_0}\right)$
Ideal gas region
Transition region
Soft gas region

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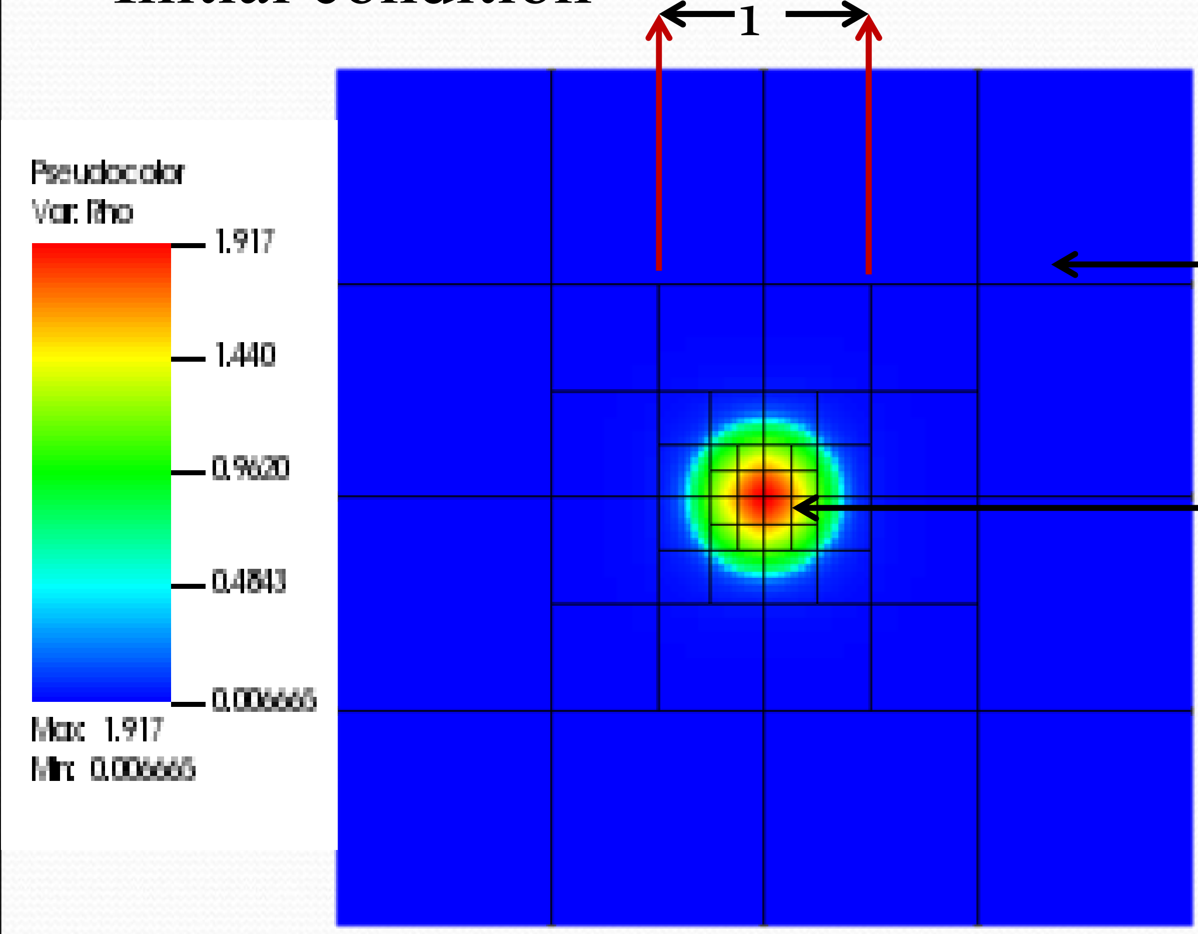
Result

- Initial condition



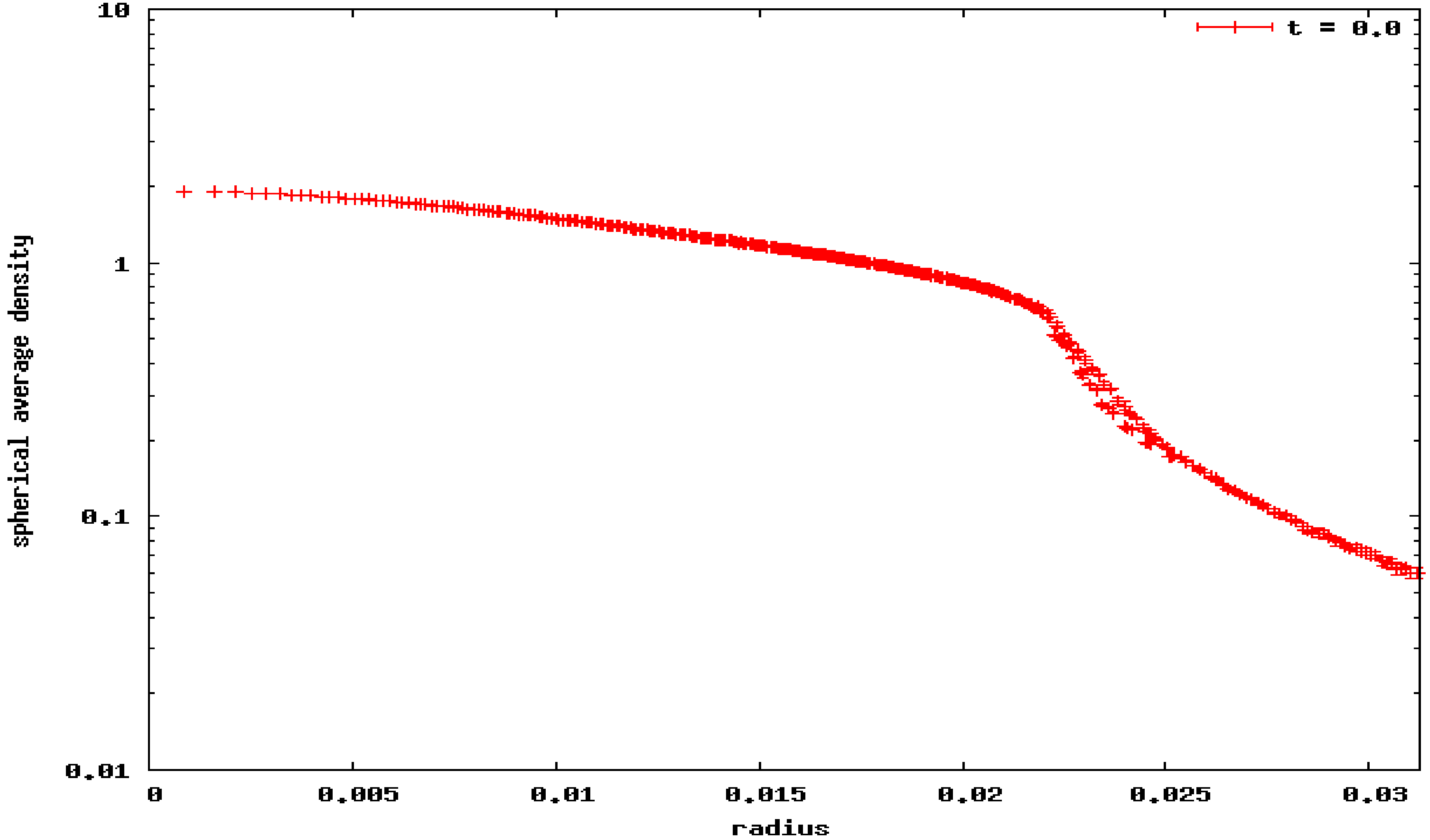
Uniform surrounding gas
$\rho_{gas} \cong 0.078\ \rho_0$

Spherical molecular cloud
with Radius R=1

No velocity field

$$\frac{Cs_{gas}}{Cs_{cloud}} \cong 20.00$$

※ The molecular cloud is at the soft gas region.
The surrounding gas is at the ideal gas region.

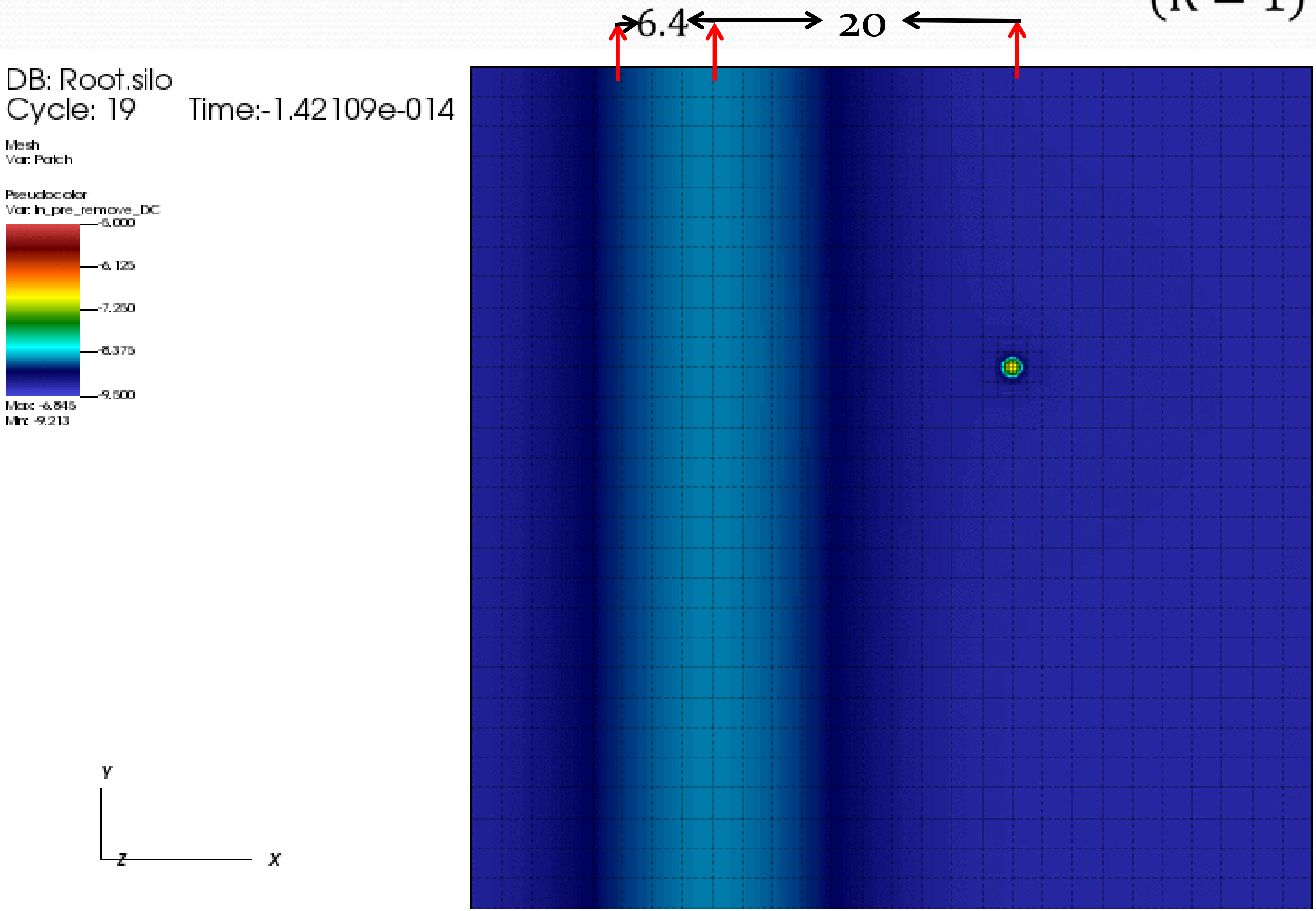


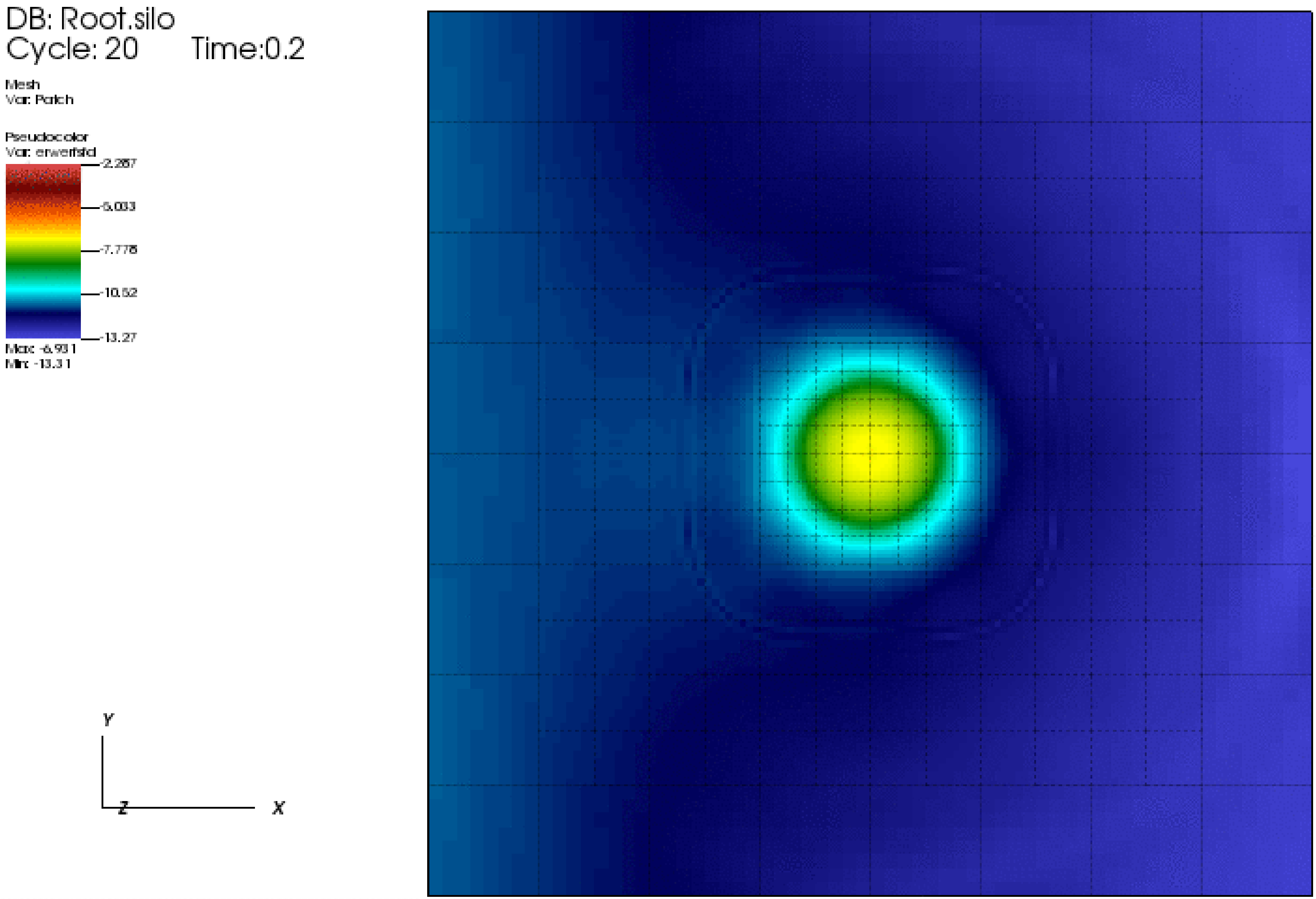
R=1

※ Characteristic period ≡ t_{ch}=1

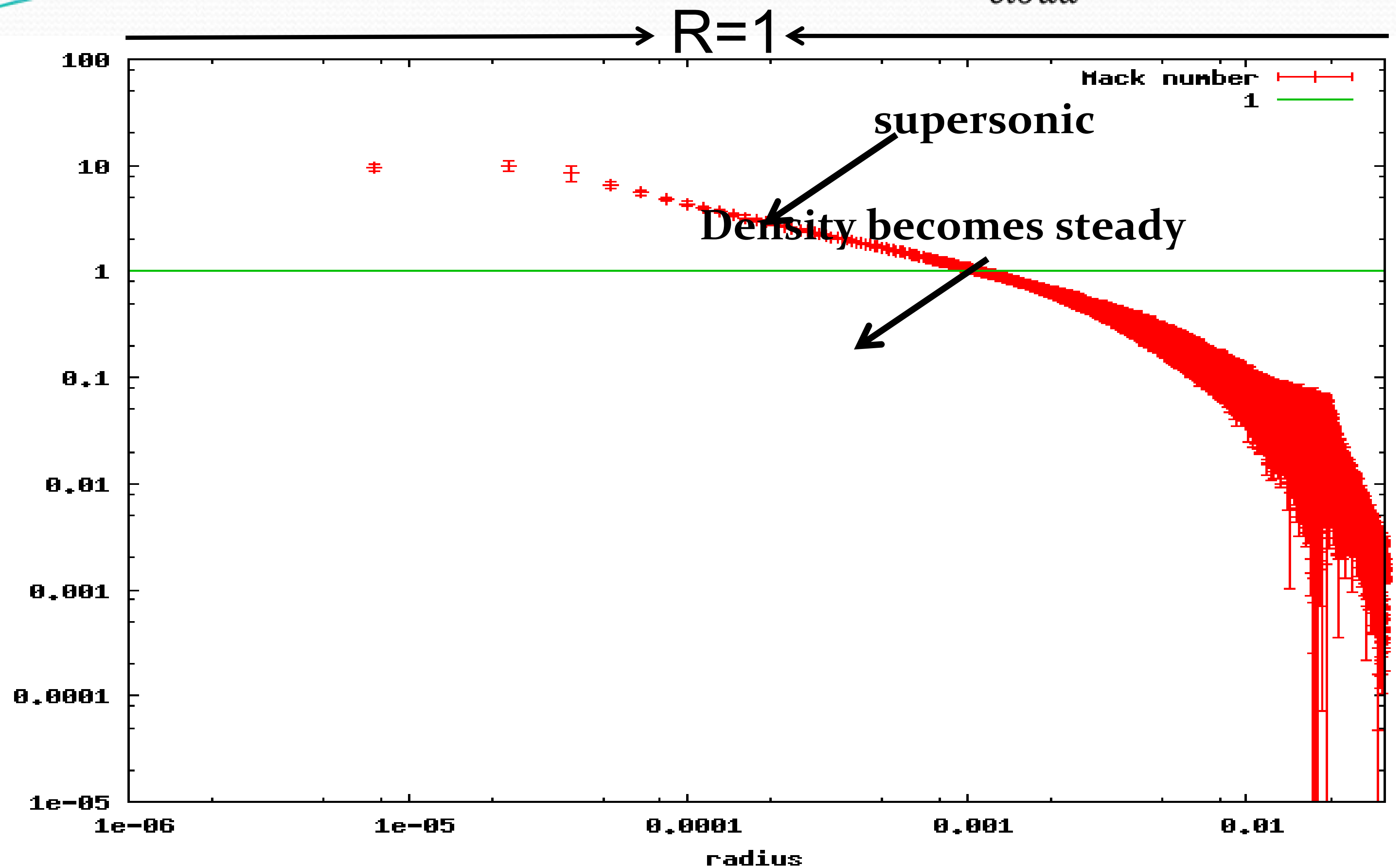
Gaussian traveling plane wave with amplitude $\delta\rho$=0.055 ρ_{gas}

(R = 1)




DB: Root.silo
Cycle: 20
Time:0.2
Mesh
Var: Patch
Pseudocolor
-2.287
-5.033
-7.778
-10.52
-13.27
Max: -6.931
Min: -13.31
Y
Z
X

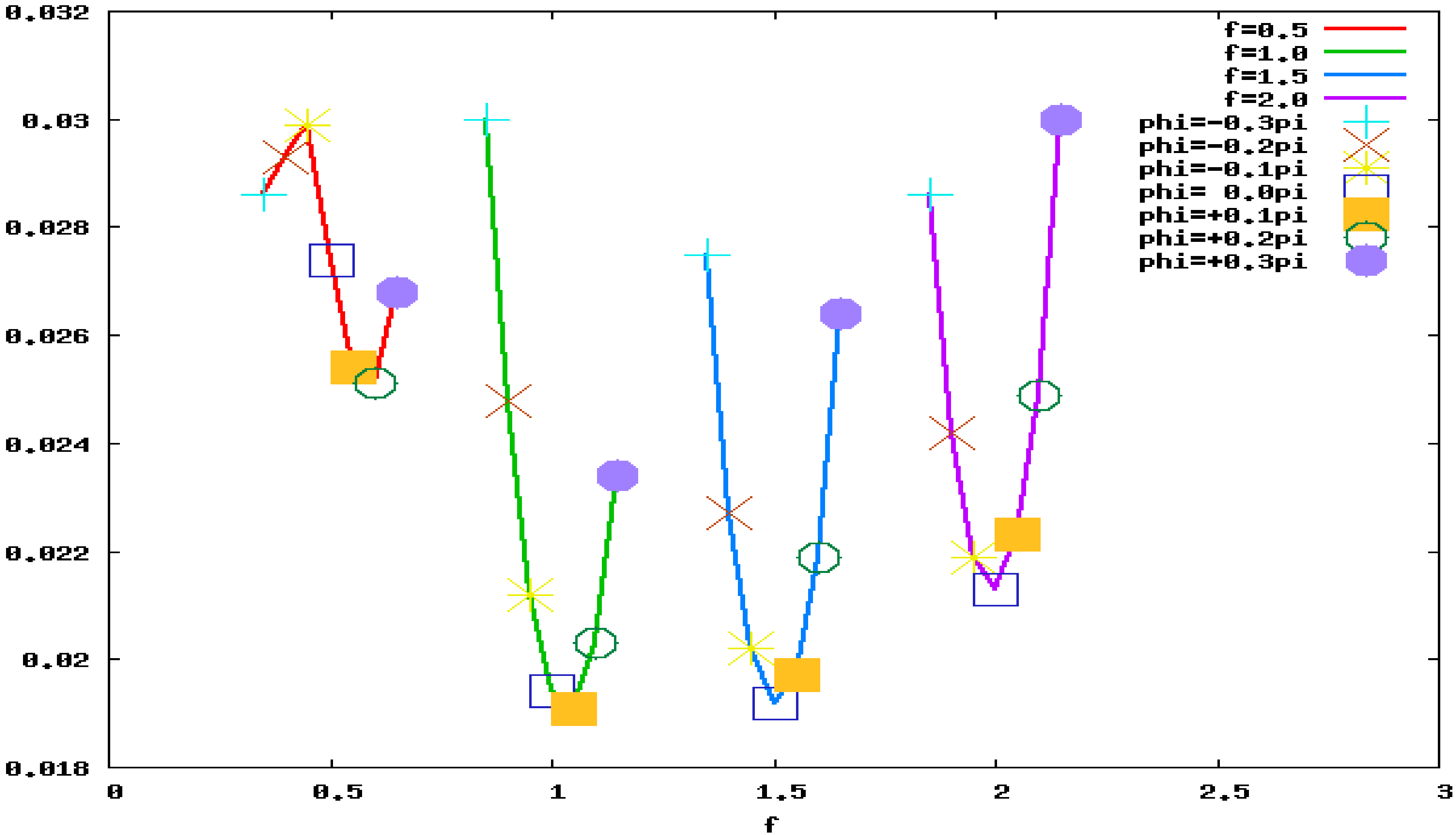
$Radial\ mass\ flux \equiv r^2 \rho V_r$; $Mach\ number \equiv \frac{|V_r|}{Cs_{cloud}}$;t=0.936



Collapse!

Standing wave : $\rho_{per}=\delta\rho \sin(kx)\cos(2\pi f t + \phi)$

$$min\frac{\delta\rho}{\rho_{gas}}=g(f,\phi)$$



Conclusions

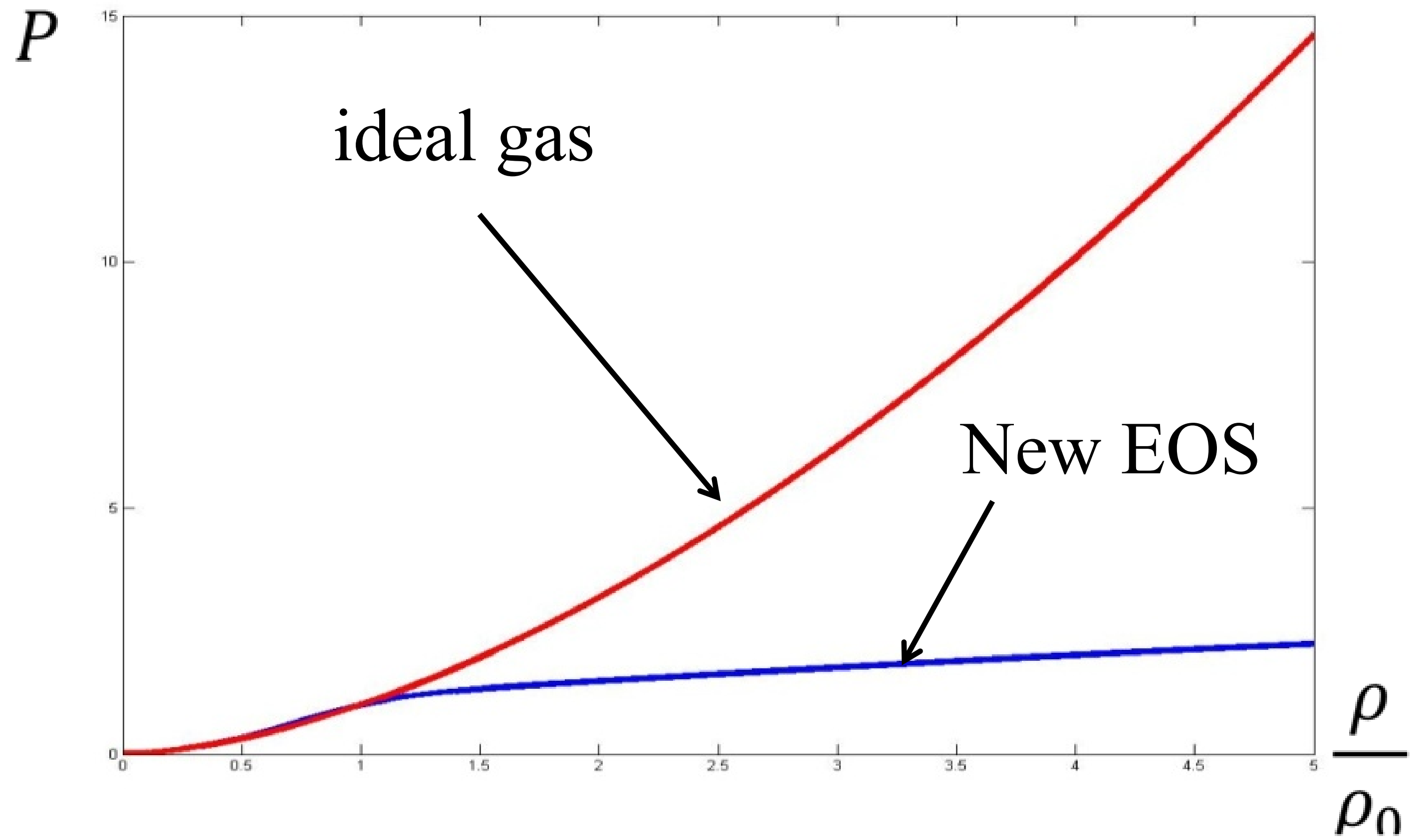
(1) Sonoluminescence mechanism can trigger the molecular cloud prompt collapse

(2) The mechanism depends on the frequency and phase. However, the resonance spectrum is broad band.

(3) The cloud collapses supersonically, and the mass flux is stationary during collapse.

(4) An irregular cloud can also be subject to triggered collapse, but with a somewhat higher (< 20%) amplitude.

Thank you



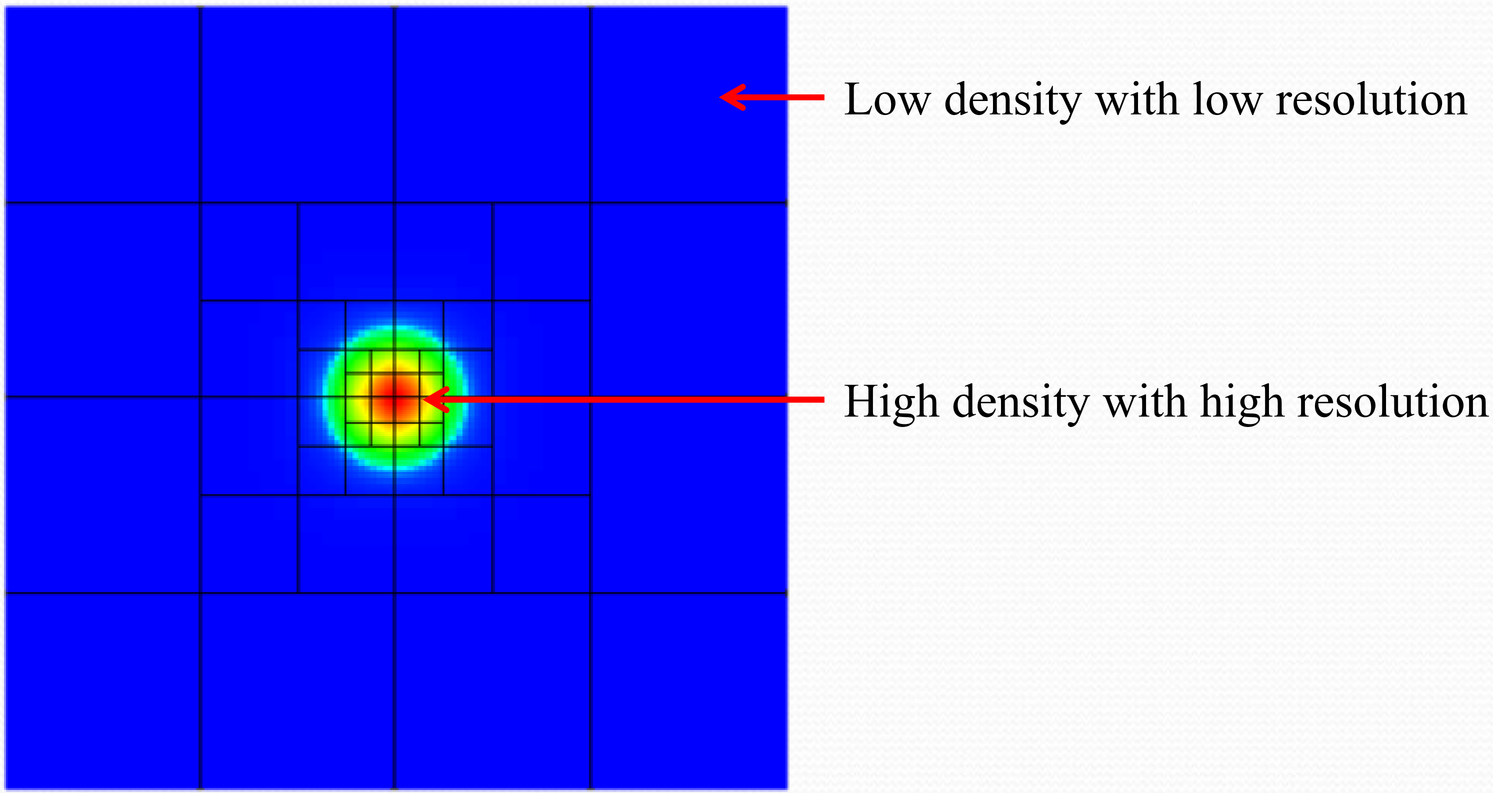
(1) Almost the same in the low density region.

(2) When the density increases, the pressure in new EOS is always smaller than ideal gas (γ=5/3).

→ Agrees that the fluid would radiate more photons in high density than low density.

Use **GAMER** code to solve above equations

GAMER: **G**PU-accelerated **A**daptive-**ME**sh **R**efinement



Ref: Schive, H., Tsai, Y., & Chiueh, T. (2010)

Choose the unit such that

diameter $\cong$ 125PC

characteristic time $\cong 2.5 \times 10^7$yr

mass of the cloud $\cong 10^6 M_{sum}$

number density of the cloud $\cong 10^1 \sim 10^2 / _{cm^3}$

Compare numbers in the above figure with the Gaussian wave pulse. Explain the choice of gaussian width and distance