総研大物理科学研究科天文科学専攻
シミュレーション天文学　２００４．７．１３

星間ガスから星への進化. II.

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Collapse & Fragmentation of Aligned Rotator ---Initial Condition and Physical Models

- An isothermal cylindrical cloud
  - in hydrostatic ba
    (Stodolkiewicz 1

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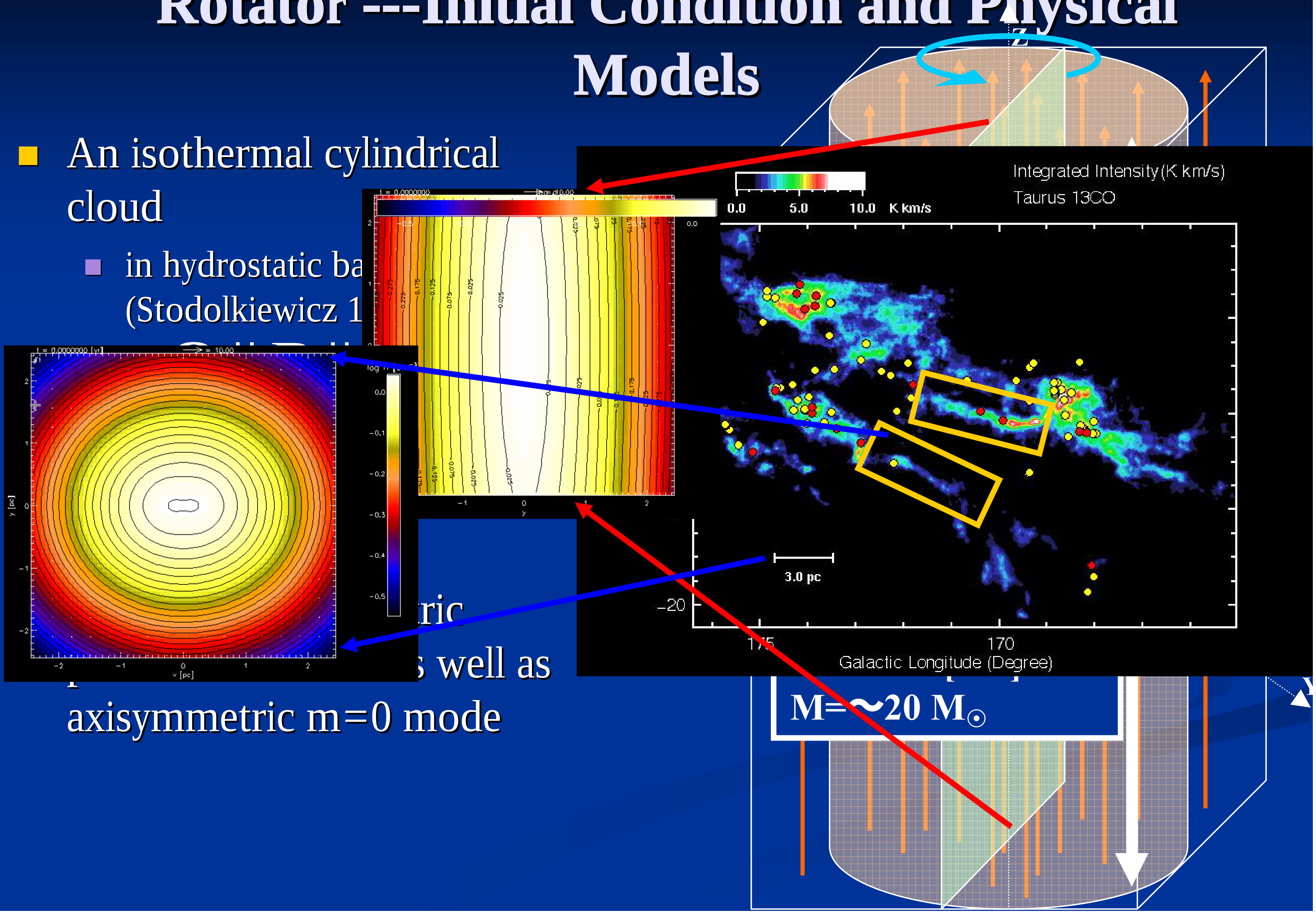
s well as axisymmetric m=0 mode



Physical Models & Numerical Method

- Ideal MHD
- Composite Polytropic Eq. of State
  - Which mimics the result of 1D RHD (eg. Masunaga, Inutsuka 2000).

$$p = c_s^2 \rho + c_s^2 \rho_{crit} \left(\rho / \rho_{crit} \right)^{7/5}$$

$$p \approx \begin{cases} c_s^2 \rho \ \ldots \ (\rho \le \rho_{crit}) & \text{Isothermal} \\ K\rho^{7/5} \ldots (\rho > \rho_{crit}) & \text{Adiabatic} \end{cases}$$

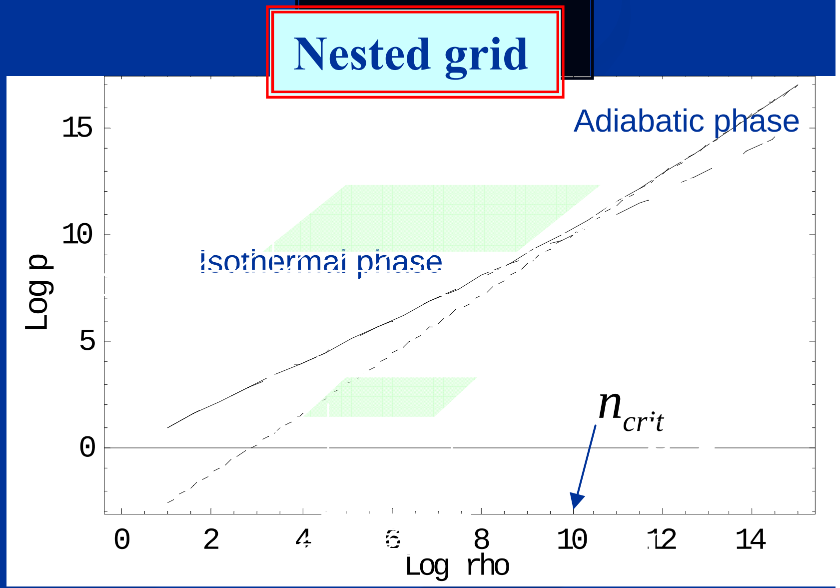
- Parameter
  - Magnetic-to-Thermal Pressure Ratio

$$\alpha = \frac{B_{0c}^2 / 4\pi}{c_s^2 \rho_{0c}}$$

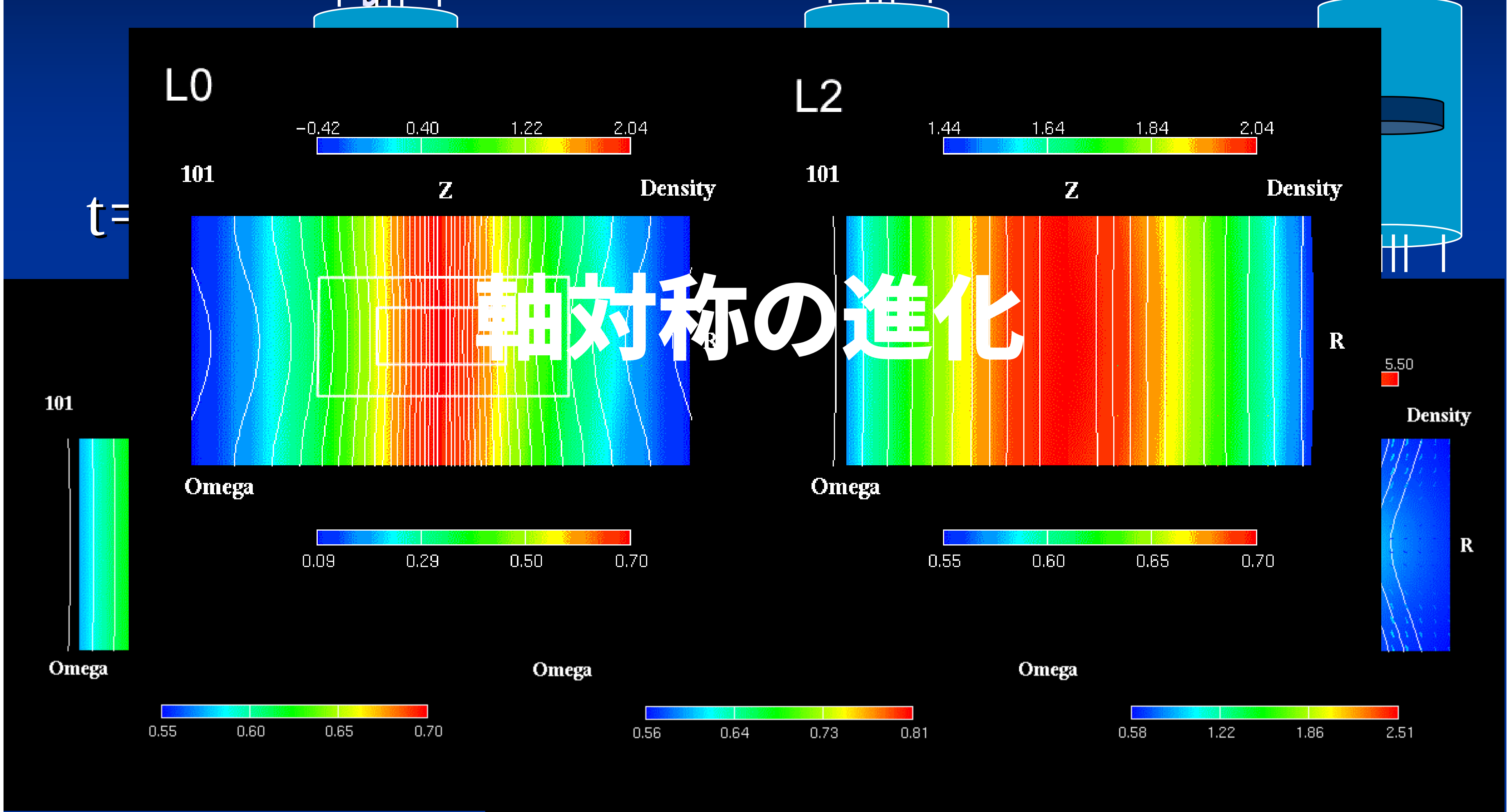
  - Angular Rotation Speed / Free-Fall Rate

$$\omega = \Omega \left(4\pi G \rho_{0c} \right)^{-1/2}$$

- "Nested Grid" Technique
  - Coarser grid: covers global structure
  - Finer grid: small-scale structure near the center.



Axisymmetric Evolution of Isothermal Runaway Collapse by Nested Grid MHD Simulation

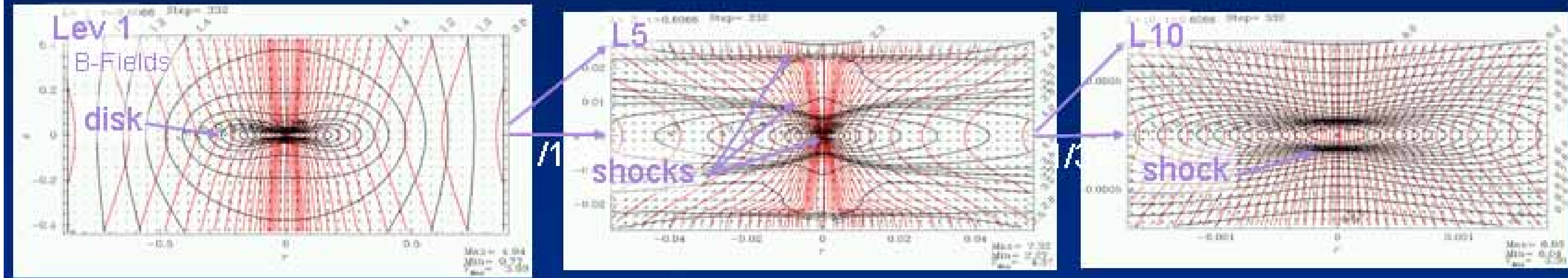


$$\alpha = 1,\ \Omega_0 = 5\ (\mathrm{L2})$$

Typical Dynamical Evolution of Rotating Magnetized Clouds

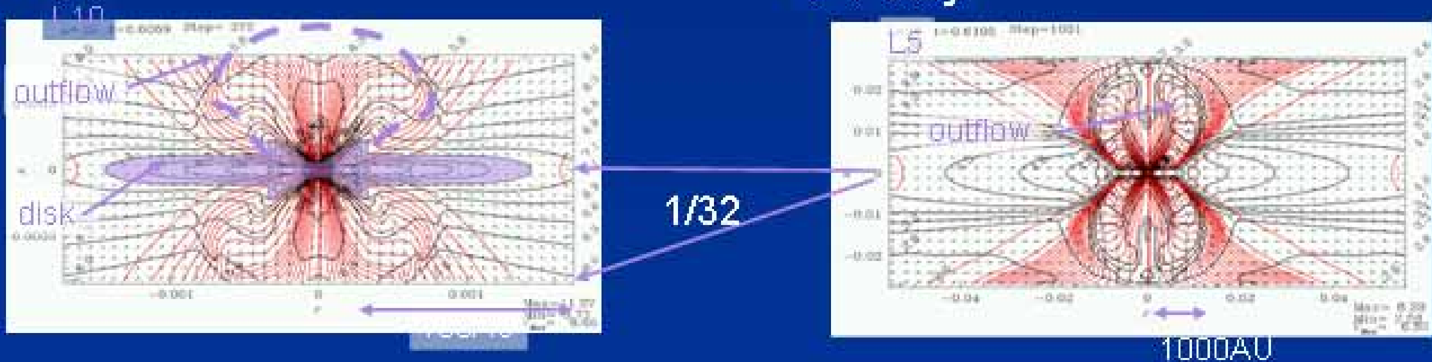
Runaway Isothermal Collapse Disk-in-disk structure.

$t=0.6066\tau_{ff}$ ~ 10^6yr after collapse begins



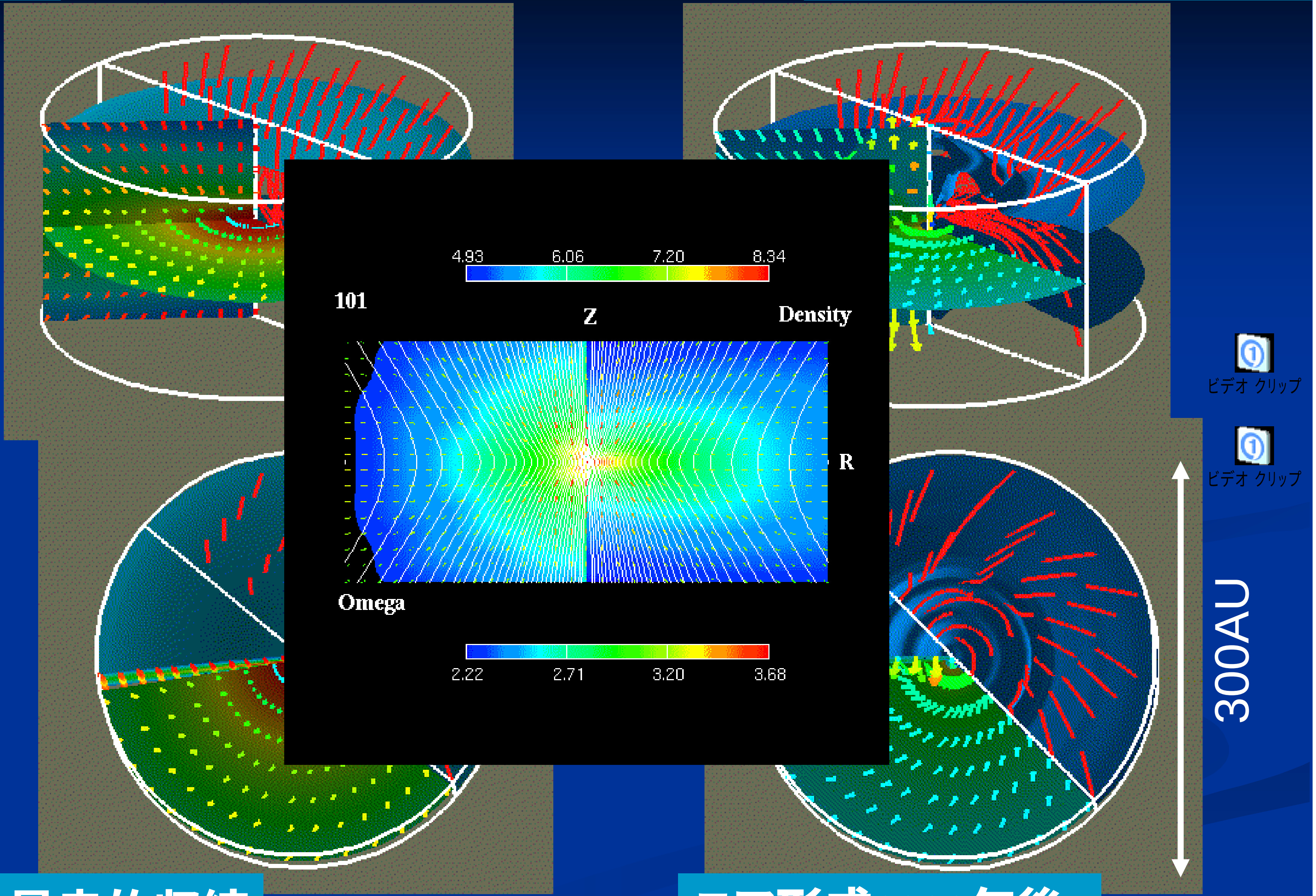
Accretion onto Adiabatic Core ($\tau=0$: core forms)

$\tau<10^3$y $\tau=7\ 10^3$y



All models with $\Omega_{cl}\neq0$ and $\alpha\neq0$ show indicate outflows.

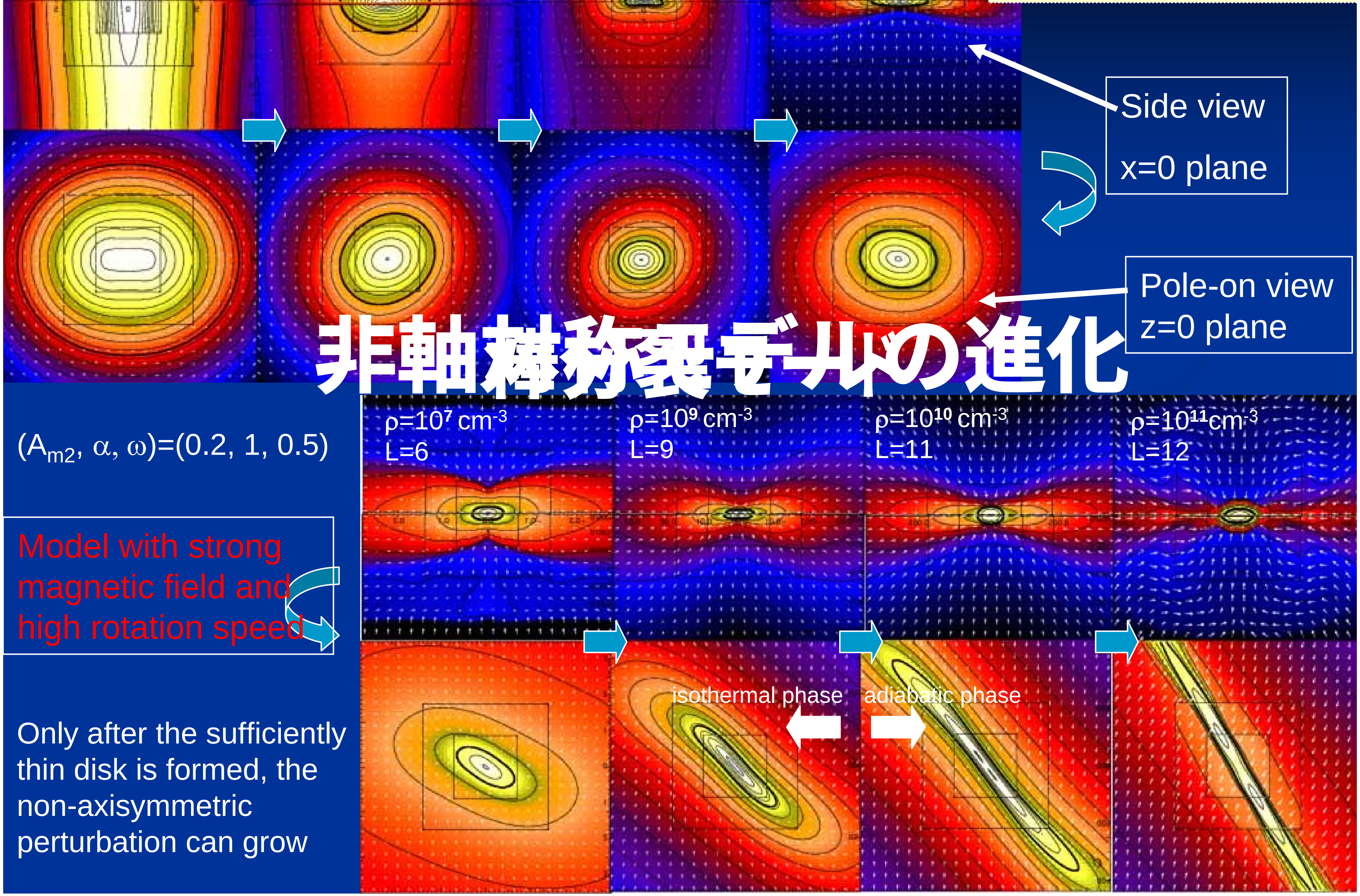
降着期　α=1, Ω=5　磁場あり、回転あり



暴走的収縮　コア形成1000年後

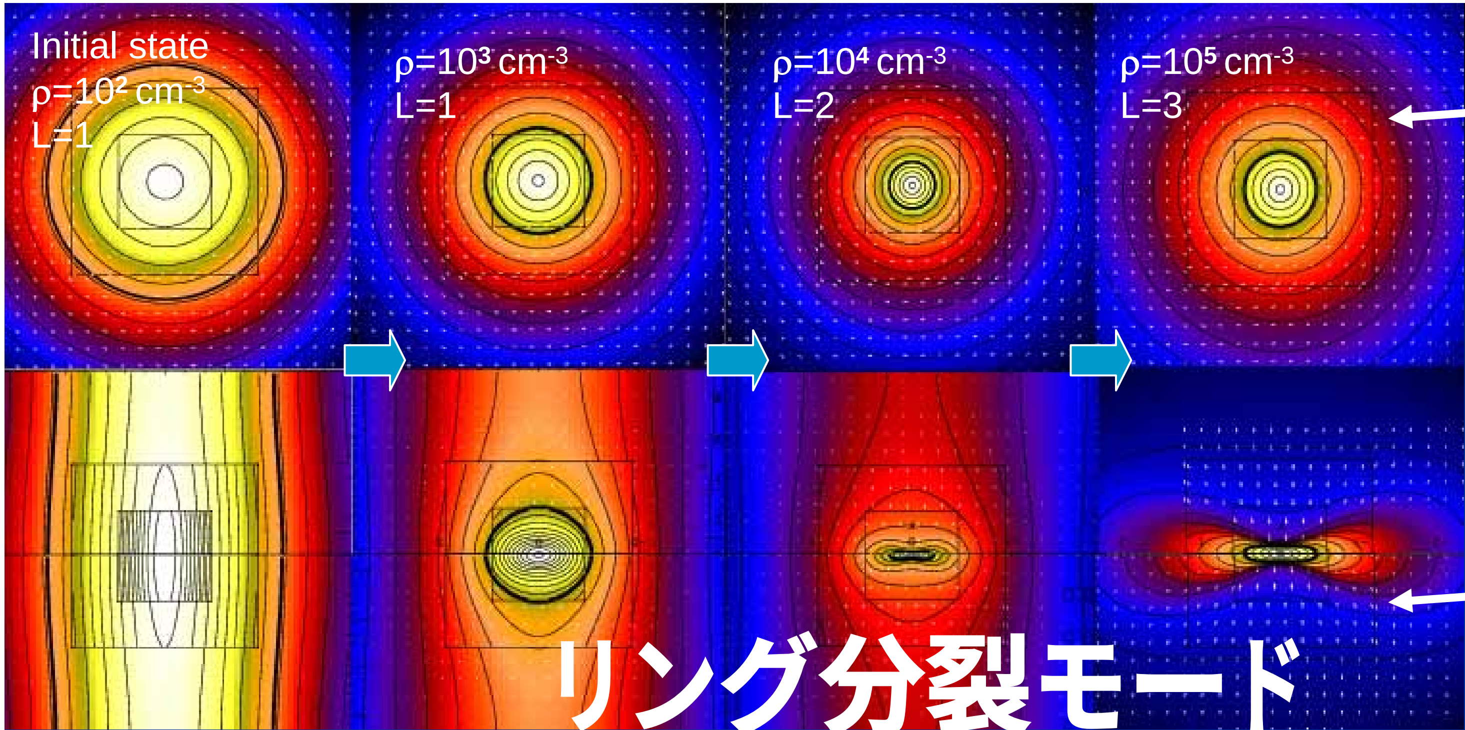
Tomisaka 1998 ApJL **502**, L163

3.Results



Initial state
ρ=10^2 cm^{-3}
L=1
ρ=10^3 cm^{-3}
L=1
ρ=10^4 cm^{-3}
L=2
ρ=10^5 cm^{-3}
L=3
Side view
x=0 plane
Pole-on view
z=0 plane
非軸対称モデルの進化
(A_{m2}, α, ω)=(0.2, 1, 0.5)
ρ=10^7 cm^{-3}
L=6
ρ=10^9 cm^{-3}
L=9
ρ=10^{10} cm^{-3}
L=11
ρ=10^{11}cm^{-3}
L=12
Model with strong magnetic field and high rotation speed
isothermal phase
adiabatic phase
Only after the sufficiently thin disk is formed, the non-axisymmetric perturbation can grow

リング分裂モード



Pole-on view

z=0 plane

Model with weak magnetic field and high rotation speed

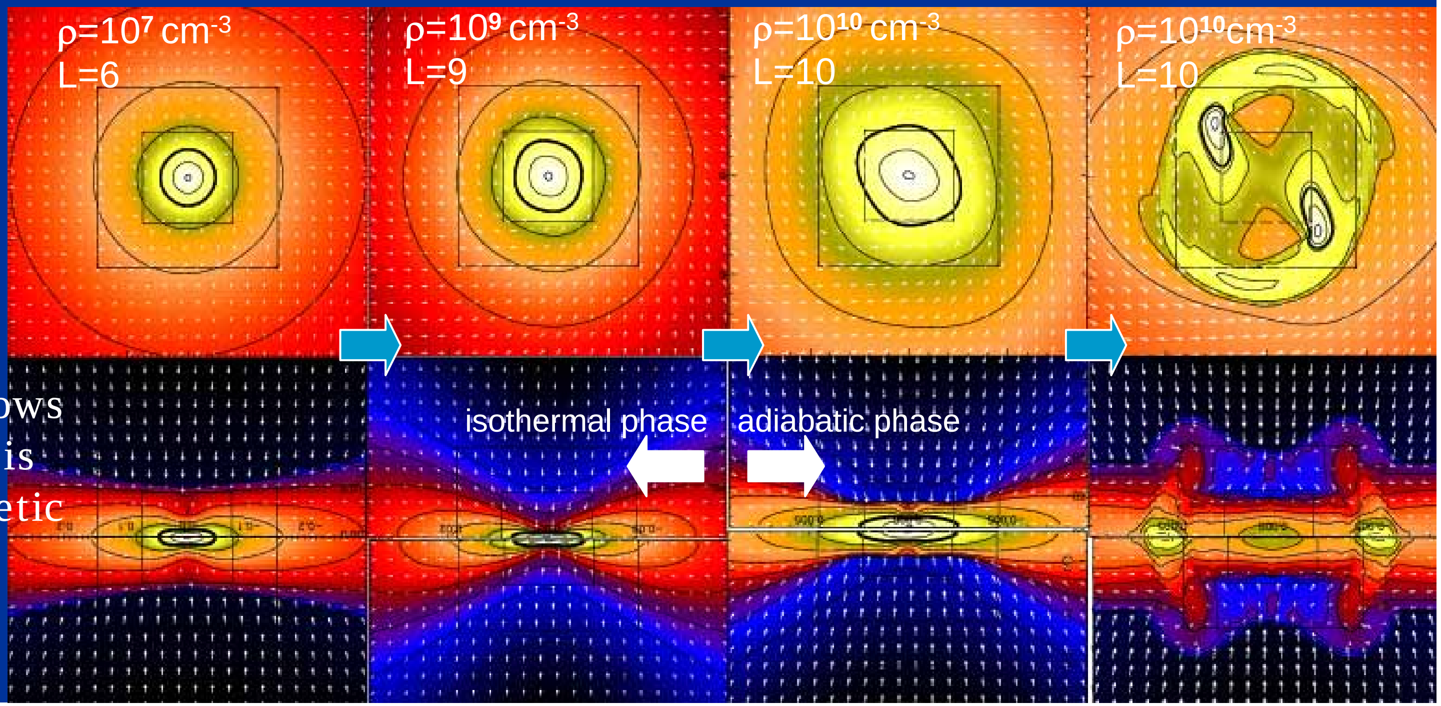
Side view

x=0 plane

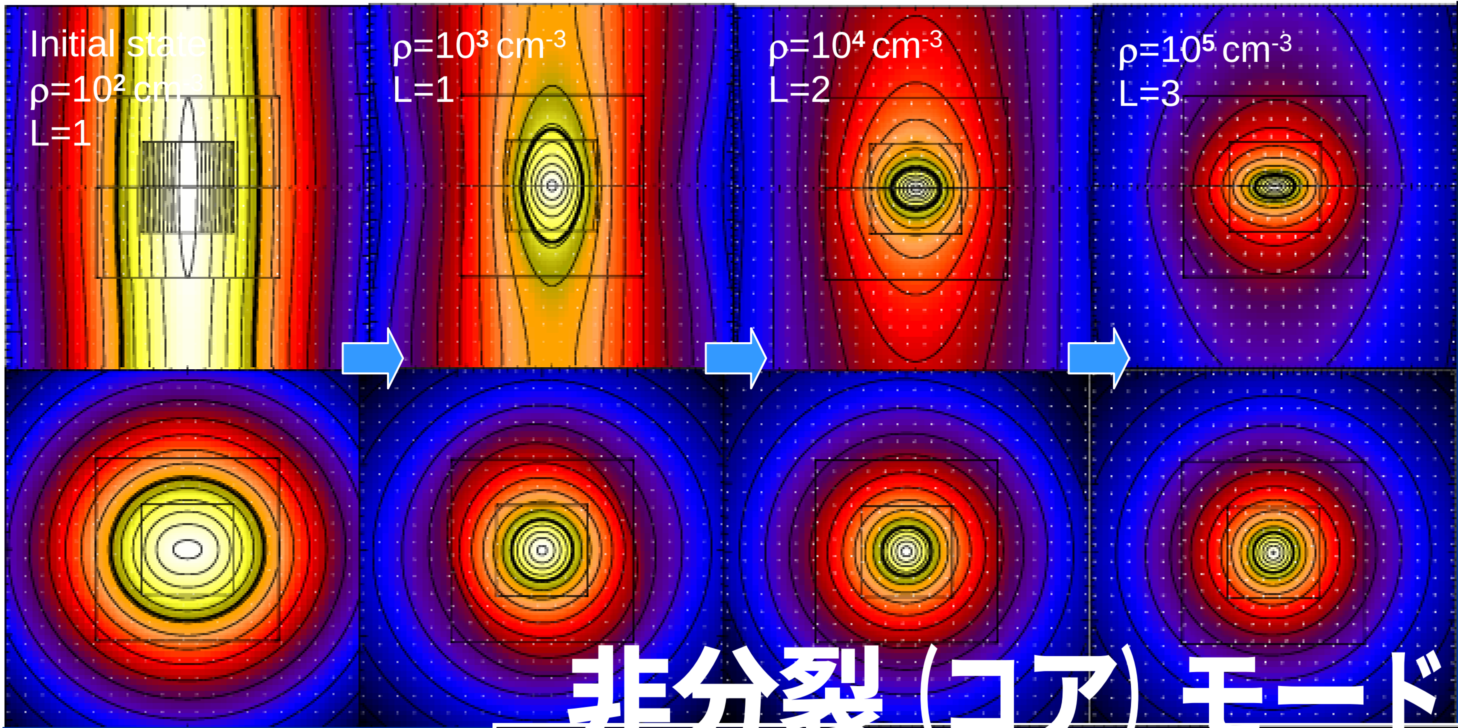
Typical Model

$(A_{m2}, \alpha, \omega)=(0.01, 0.01, 0.5)$

In this model, the non-axisymmetry hardly grows because disk formation is delayed for weak magnetic fields.



非分裂（コア）モード

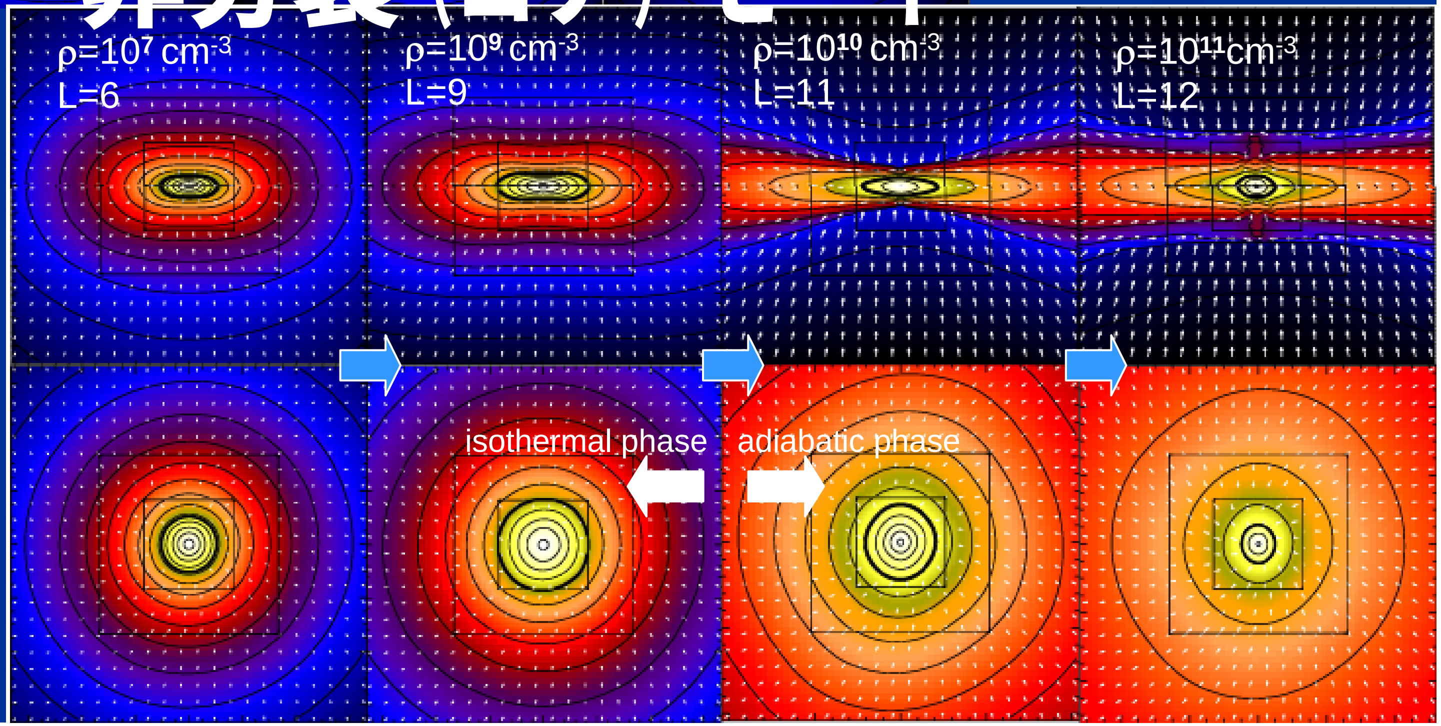


This corresponds to strong B-field & slow rotation.

Disk -->
Spherical core

Core Model

(A_{m2}, α, ω)=(0.01, 1, 0.1)



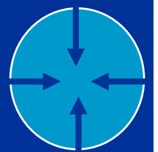
Ω≠0, B≠0 (Machida et al 2004 MN in press)

- On convergence:

$$\frac{\left[\Omega_c/(2\pi G\rho_c)^{1/2}\right]^2}{0.3^2}+\frac{\left(B_c/2\pi G^{1/2}\Sigma_c\right)^2}{1}=1$$

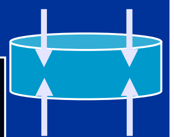
- Spherical collapse

$$\Omega_c \propto R^{-2} \propto \rho^{2/3} \Rightarrow \Omega_c/\rho_c^{1/2} \propto \rho_c^{1/6}$$
$$B_c \propto R^{-2} \propto \rho^{2/3} \Rightarrow B_c/\rho_c^{1/2} \propto \rho_c^{1/6}$$
$$\therefore (\Omega_c/\rho^{1/2}) \propto (B_c/\rho_c^{1/2})$$

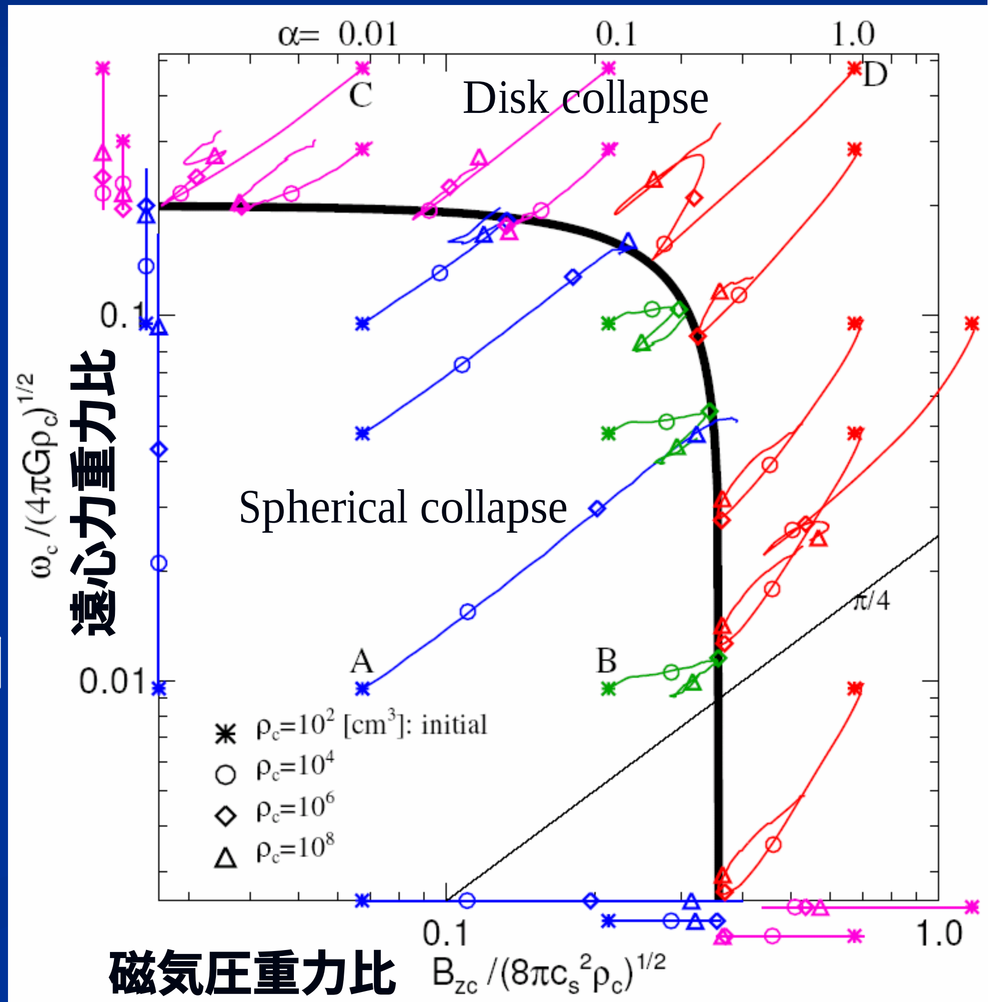


  - **右上方向45度へ進化**
- **磁気ブレーキ**
  - **磁場による角運動量の外部への輸送**
  - **$\Omega/\rho^{1/2}$の抑制**
- Disk collapse

$$\Omega_c \sim \text{const} \Rightarrow \Omega_c/(4\pi G\rho_c)^{1/2} \propto \rho_c^{-1/2}$$
$$B_c \sim \text{const} \Rightarrow B_c/(8\pi c_s^2\rho_c)^{1/2} \simeq \rho_c^{-1/2}$$
$$\therefore (\Omega_c/\rho^{1/2}) \propto (B_c/\rho_c^{1/2})$$



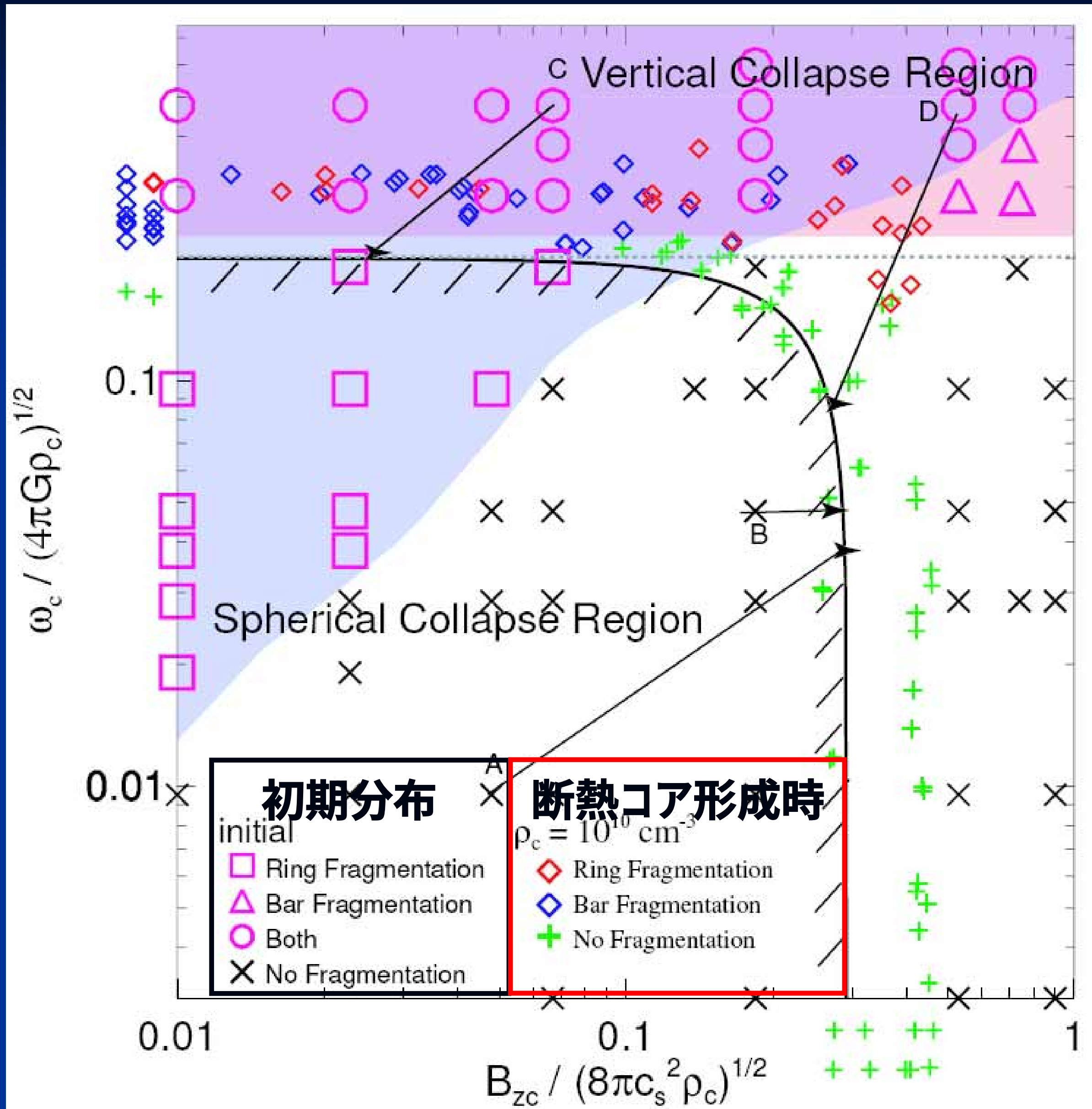
  - **左下方向45度へ進化**



分裂条件：
$\Omega_c/(4\pi G\rho_c)^{1/2}>0.2$
@断熱コア形成時

初期条件→分裂時の条件：45度の直線上

分裂する領域はブルーに着色した領域

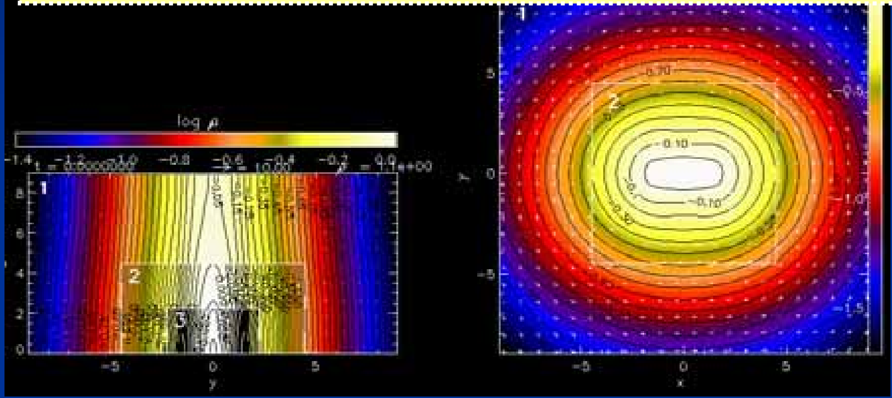


Modes of Fragmentation

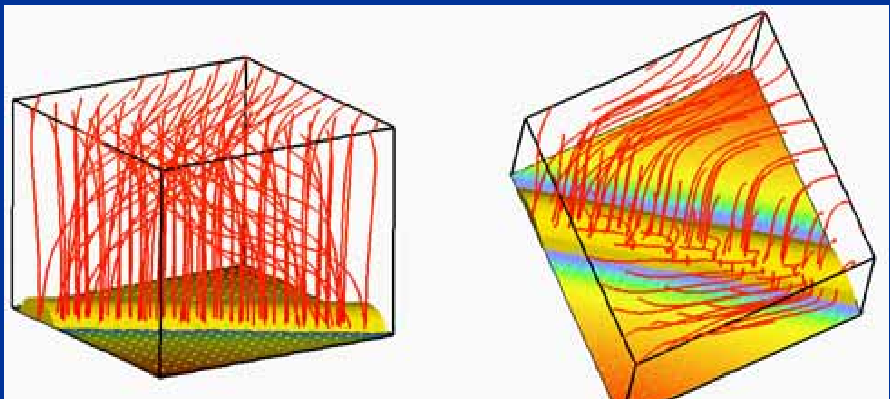
Core type

bar fragmentation

: A_{m2}=0.2 α=1.0 ω=0.5



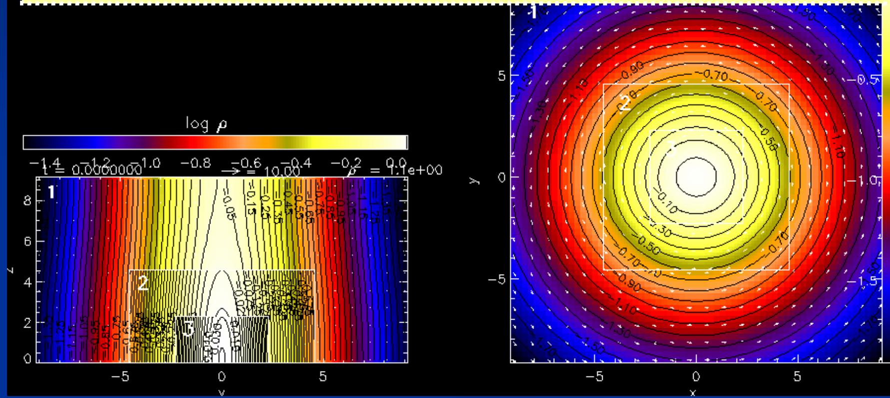
density (false color, contour)
velocity (arrows)



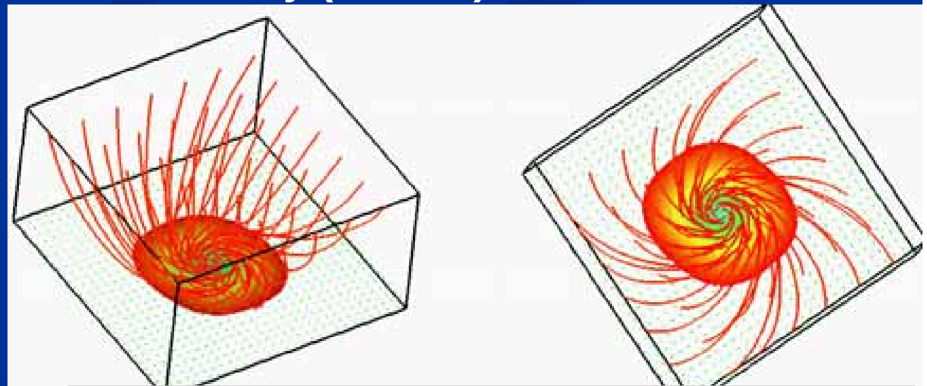
Shape of the magnetic field line
(red stream lines)
outflow region(blue isovolume)

ring fragmentation

: A_{m2}=0.01 α=0.01 ω=0.5



density (false color, contour)
velocity (arrows)



Shape of the magnetic field line
(red stream lines)
outflow region(blue isovolume)

シミュレーション研究の進展

- 問題の定式化
- 実験装置であるプログラムについて、適当な計算法を検討
  - 数値不安定性
- プログラムの作成、テスト (検証)
  - 検証問題：類似問題で既知の解のある問題
    - 衝撃波管問題、自己相似解、定常問題の解
- 計算の実行
- 計算結果の解析
  - シミュレーションの可視化、アニメーション
  - 結果から誘導される単純な量の間の関係
  - 物理的解釈
- 結果をわかりやすい形で発表