SKA-JP
Square Kilometre Array
Japanese Consortium

TOHOKU
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A Galactic Dynamo in Spiral Galaxies: Effects of Steady Spiral Arms and their Pattern Speeds

Sho NAKAMURA, Makoto HATTORI (Tohoku Univ.)

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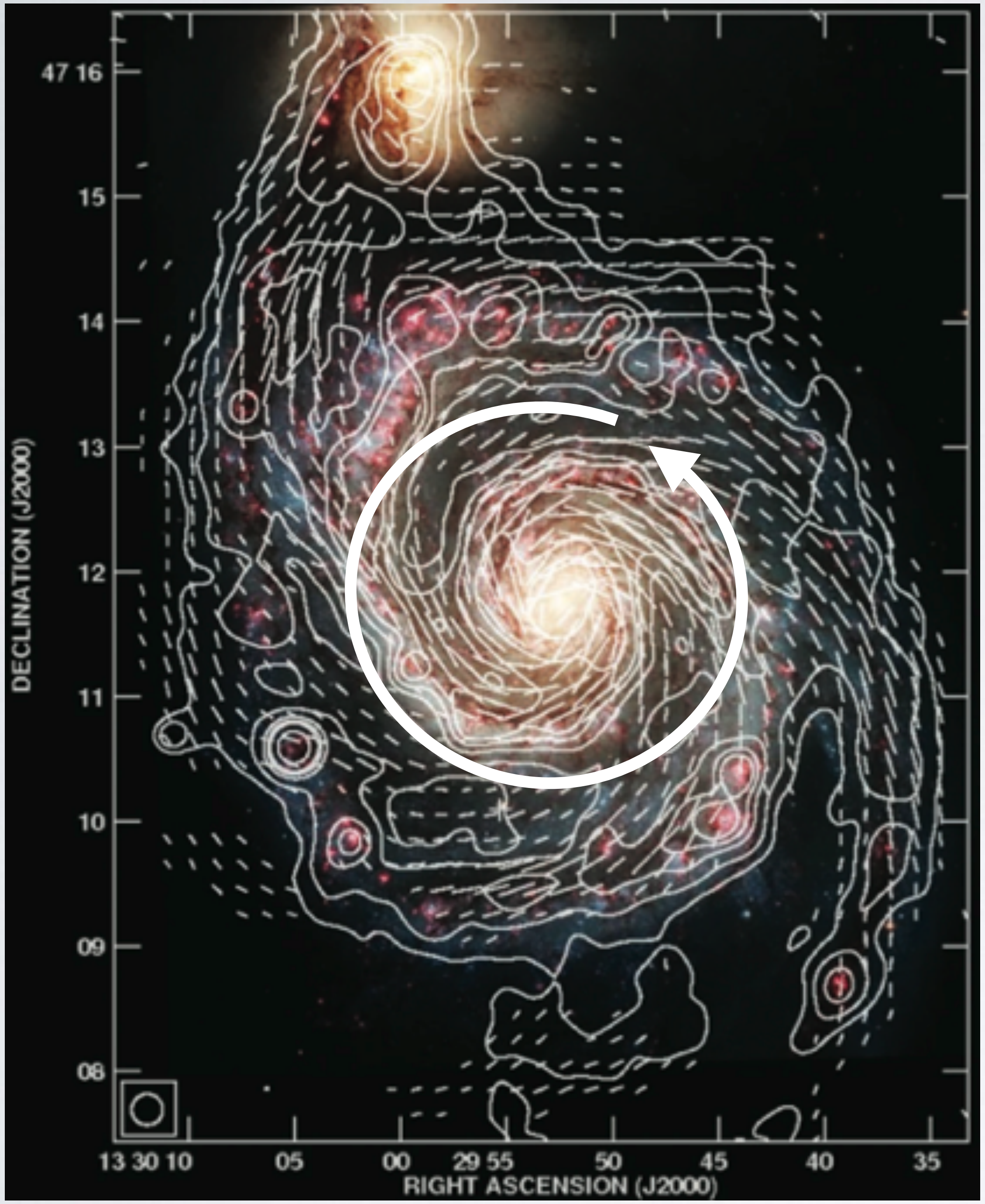
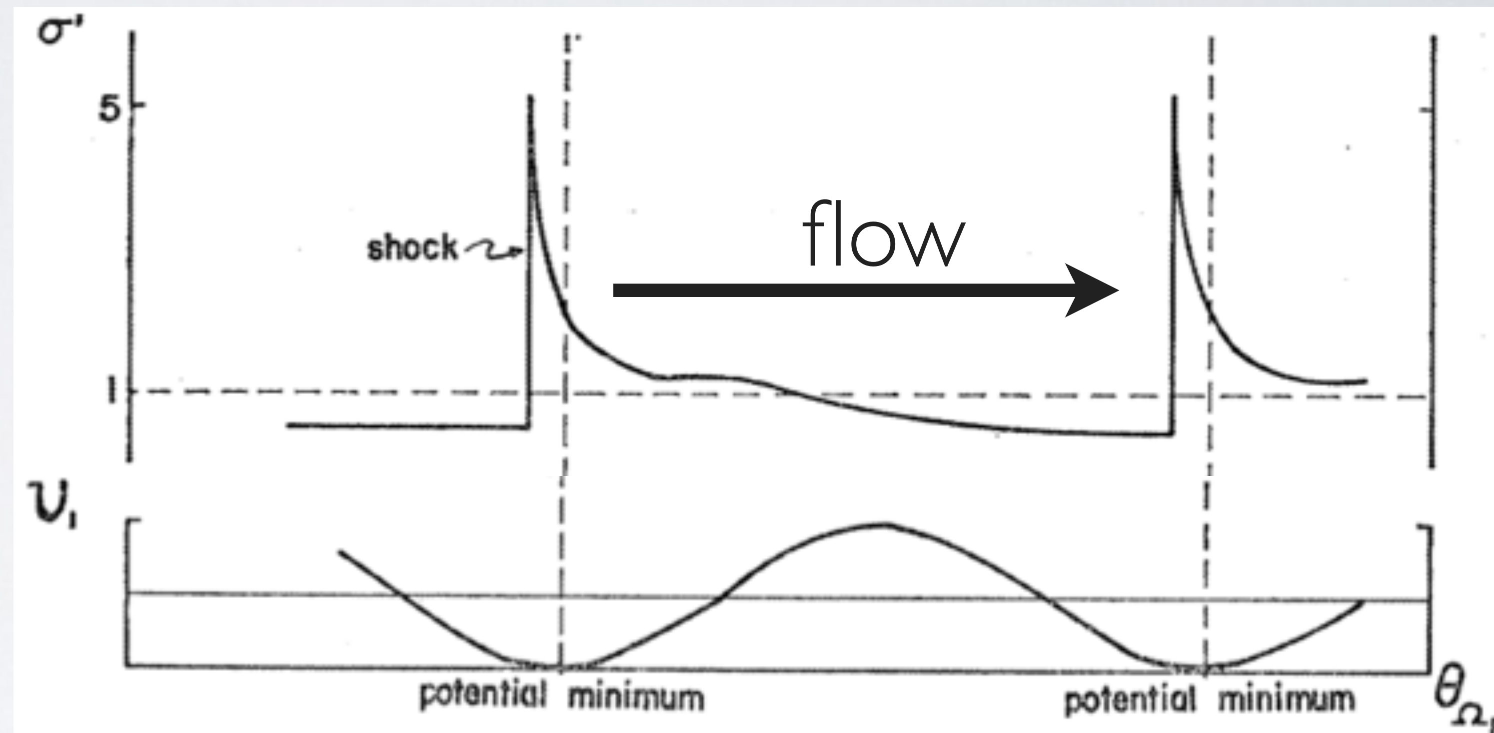
Introduction

Grand-design Spiral Galaxies





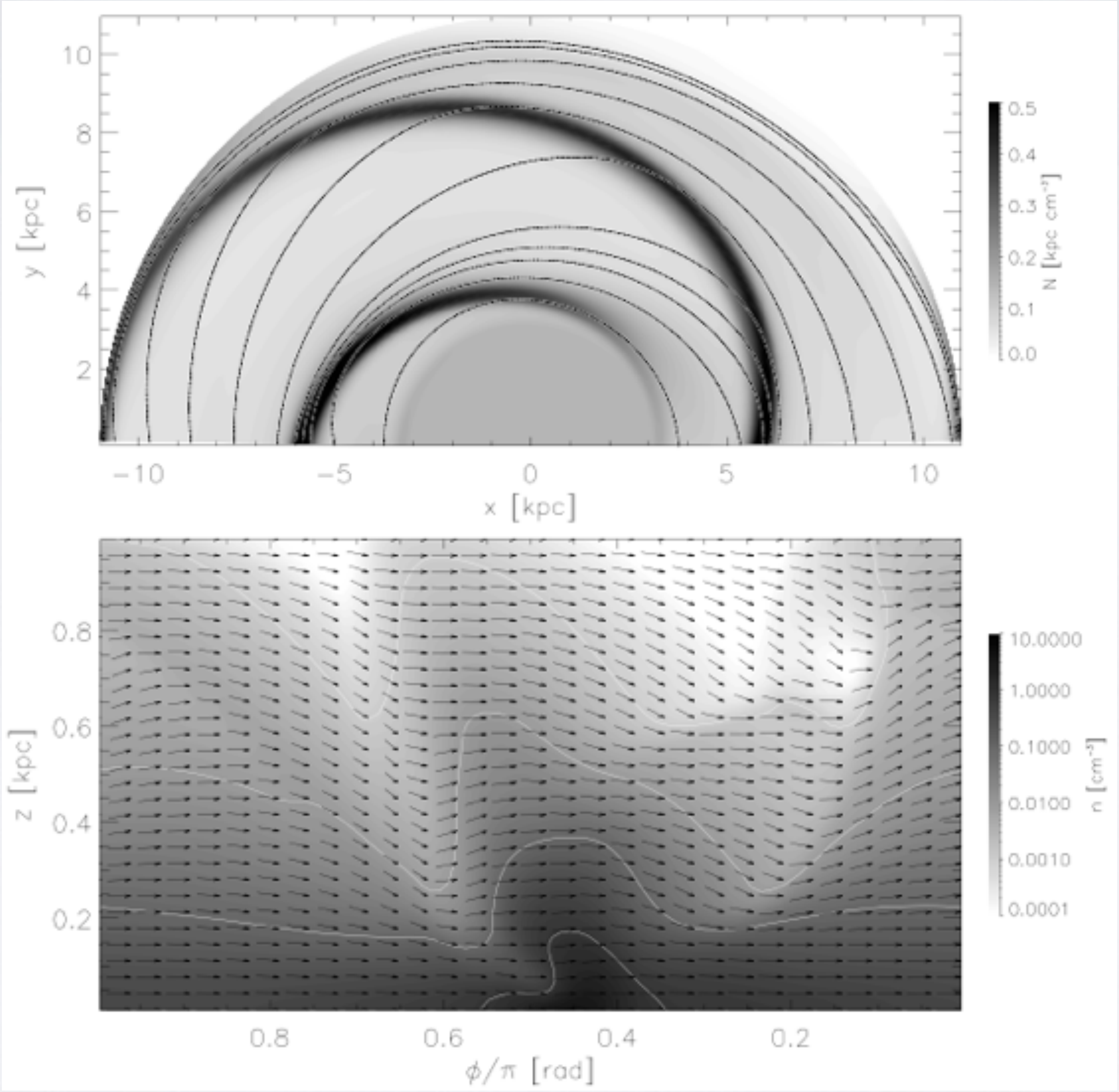
Roberts, 1969

Fletcher+, 2011
(M51, λ=6cm)

Spiral galaxies have magnetic fields along the spiral arms
@ galactic plane.

Introduction
Previous Work

Previous Work



Gomez & Cox, 2002

isothermal, initial B ~ a few μG

Motivation

Motivation

渦状腕があると

1. 磁場の進化
2. 最終的に出来る磁場の幾何構造

にどのような影響を与えるか、実際にシミュレーションした。

Model

&

Methods

Model: Basic Equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot \left\{ \rho \mathbf{u}\mathbf{u} + \left(p_{\rm gas} + \frac{1}{8\pi} B^2 \right) \mathbf{I} - \frac{1}{4\pi} \mathbf{B}\mathbf{B} \right\} = \boxed{-\rho \nabla \Phi} + \rho \Omega_{\rm sp}^2 \mathbf{R} - 2\rho \boldsymbol{\Omega}_{\rm sp} \times \mathbf{u}$$

$$\frac{\partial e}{\partial t} + \nabla \cdot \left[\left\{ e + \left(p_{\rm gas} + \frac{1}{8\pi} B^2 \right) \right\} \mathbf{u} - \frac{1}{4\pi} (\mathbf{B} \cdot \mathbf{u}) \mathbf{B} \right] = \mathbf{u} \cdot (\boxed{-\rho \nabla \Phi} + \rho \Omega_{\rm sp}^2 \mathbf{R}) - \rho^2 \Lambda (T_{\rm gas})$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \cdot (\mathbf{u}\mathbf{B} - \mathbf{B}\mathbf{u}) = \mathbf{0}$$

$$e_{\rm gas} = \frac{p_{\rm gas}}{\gamma_{\rm gas} - 1}, \ \gamma_{\rm gas} = 5/3, \ e = \frac{1}{2}\rho u^2 + e_{\rm gas} + \frac{1}{8\pi} B^2, \ \mathbf{u} = \mathbf{v} - \Omega_{sp} R \mathbf{e}_{\varphi}$$

Spiral Potential

$$\Phi(R,\varphi,z;t) = \Phi_{\rm bulge}(R,z) + \Phi_{\rm disc}(R,z) + \Phi_{\rm halo}(R,z) + \underline{\Phi_{\rm sp}(R,\varphi,z;t)}$$

non-axisymmetric potential

$$\Phi_{\rm sp}(R,\varphi,z;t) = \Phi_{\rm disc}(R,z)\epsilon_{\rm sp}\frac{(R/R_a)^2}{\{1+(R/R_a)^2\}^{3/2}}\frac{z_a}{\sqrt{z^2+z_a^2}} \times \cos\left[m\left\{\varphi - \Omega_{\rm sp}t + \cot i_{\rm sp}\ln\left(\frac{R}{R_{\rm phase}}\right)\right\}\right]$$

Wada+ 2004, Wada+ 2011

$$\epsilon_{\rm sp} = 0.025, R_{\rm a} = 7{\rm kpc}, z_{\rm a} = 0.3{\rm kpc}, m = 2, \Omega_{\rm sp} = 15{\rm kms^{-1}kpc^{-1}}, i_{\rm sp} = 15^\circ, R_{\rm phase} = 0.1{\rm kpc}$$

Model: Basic Equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot \left\{ \rho \mathbf{u}\mathbf{u} + \left(p_{\rm gas} + \frac{1}{8\pi} B^2 \right) \mathbf{I} - \frac{1}{4\pi} \mathbf{B}\mathbf{B} \right\} = -\rho \nabla \Phi + \rho \Omega_{\rm sp}^2 \mathbf{R} - 2\rho \mathbf{\Omega}_{\rm sp} \times \mathbf{u}$$

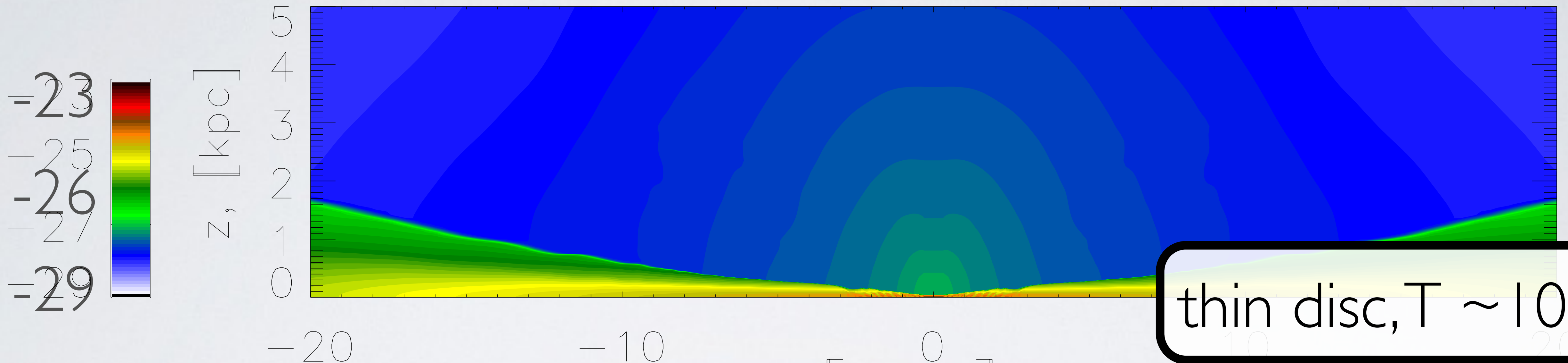
$$\boxed{\frac{\partial e}{\partial t} + \nabla \cdot \left[\left\{ e + \left(p_{\rm gas} + \frac{1}{8\pi} B^2 \right) \right\} \mathbf{u} - \frac{1}{4\pi} (\mathbf{B} \cdot \mathbf{u}) \mathbf{B} \right] = \mathbf{u} \cdot (-\rho \nabla \Phi + \rho \Omega_{\rm sp}^2 \mathbf{R}) - \rho^2 \Lambda(T_{\rm gas})}$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \cdot (\mathbf{u}\mathbf{B} - \mathbf{B}\mathbf{u}) = \mathbf{0}$$

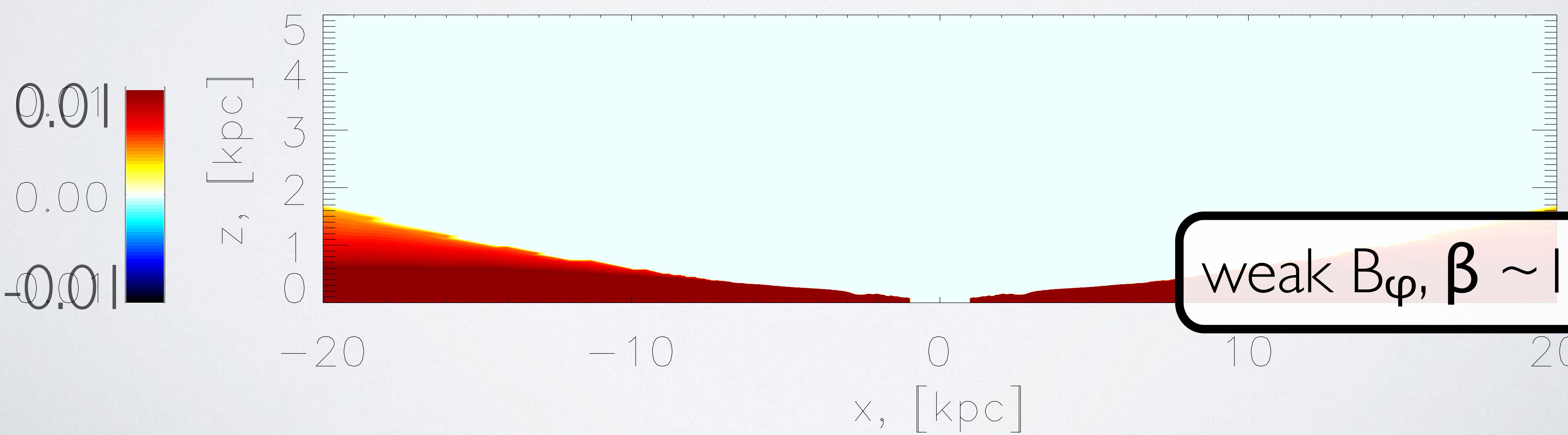
$$e_{\rm gas} = \frac{p_{\rm gas}}{\gamma_{\rm gas} - 1}, \ \gamma_{\rm gas} = 5/3, \ e = \frac{1}{2} \rho u^2 + e_{\rm gas} + \frac{1}{8\pi} B^2, \ \mathbf{u} = \mathbf{v} - \Omega_{sp} R \mathbf{e}_{\varphi}$$

Model: Initial Condition

hydrostatic halo, T ~10^6K



thin disc, T ~10^4K

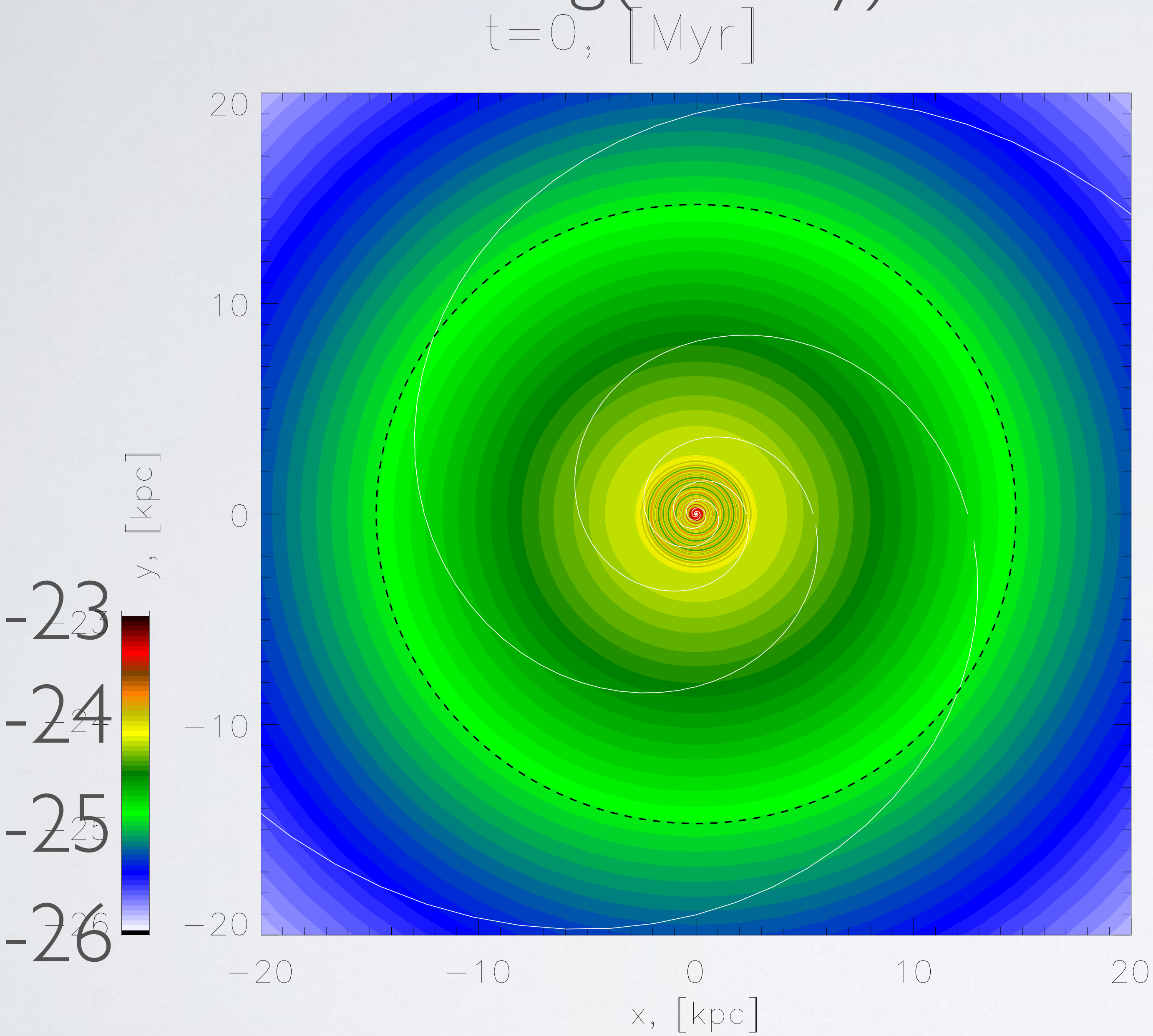


weak B_φ, β ~10^4

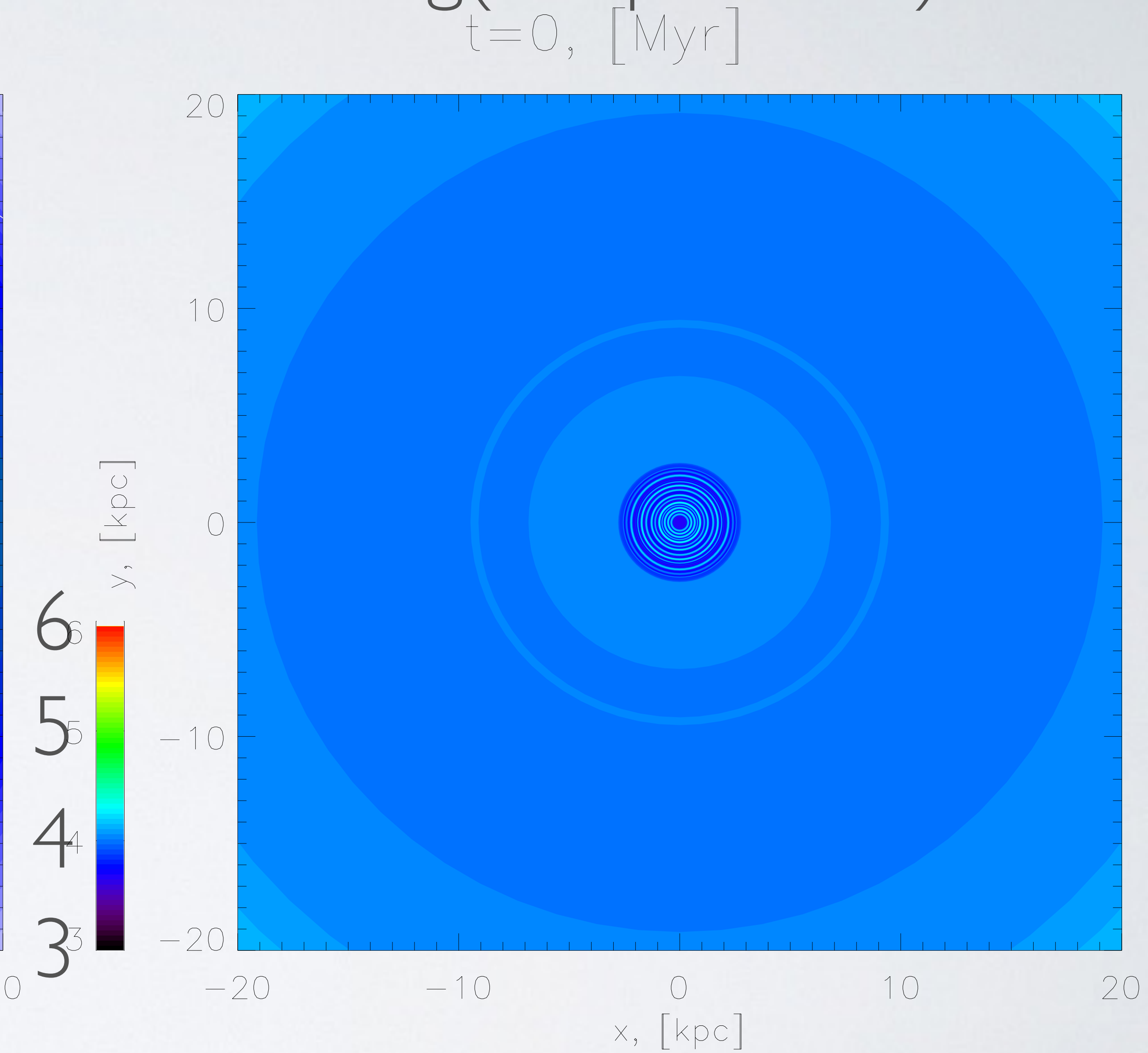
Results

Results(t=0Myr)

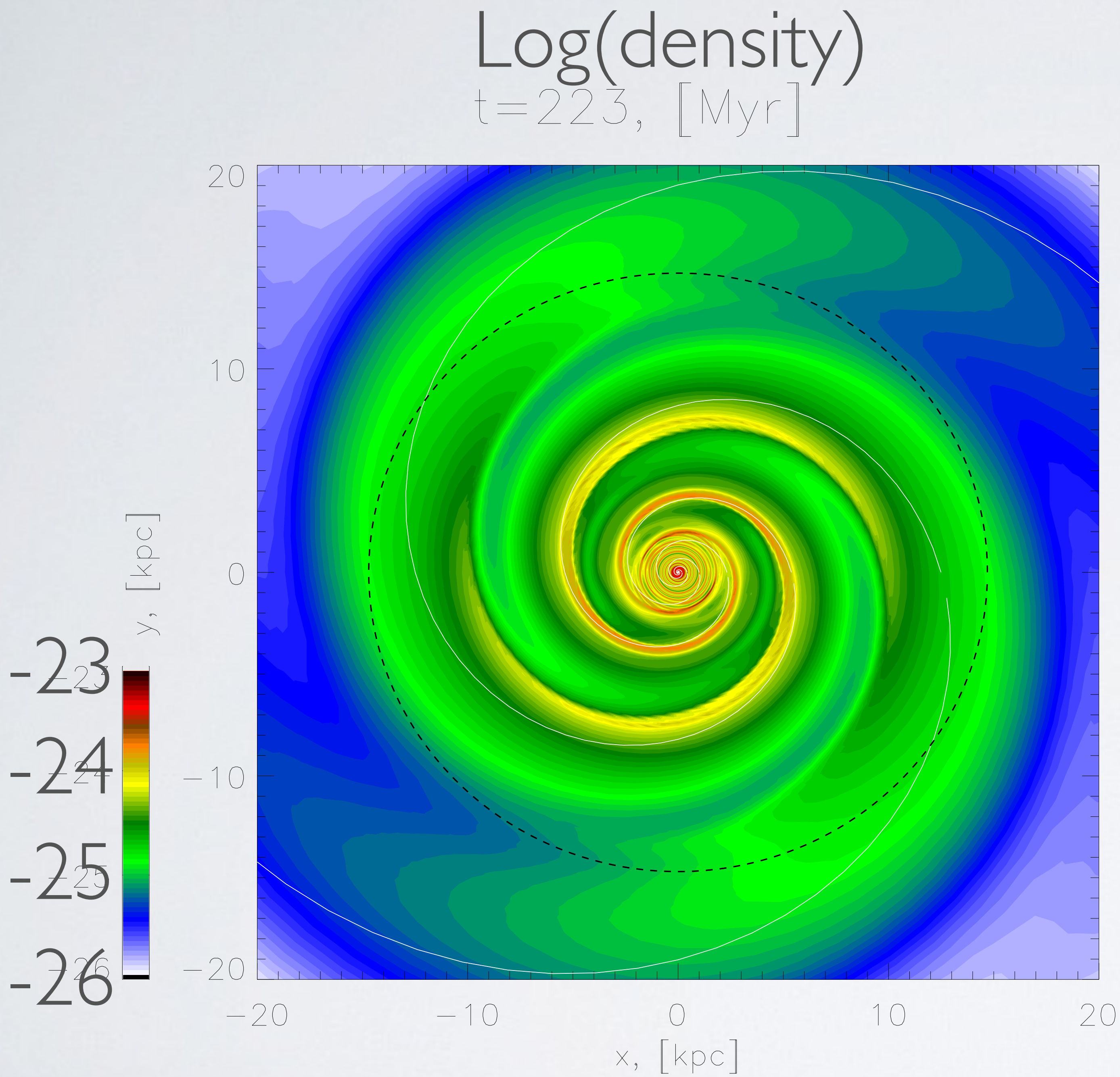
Log(density)

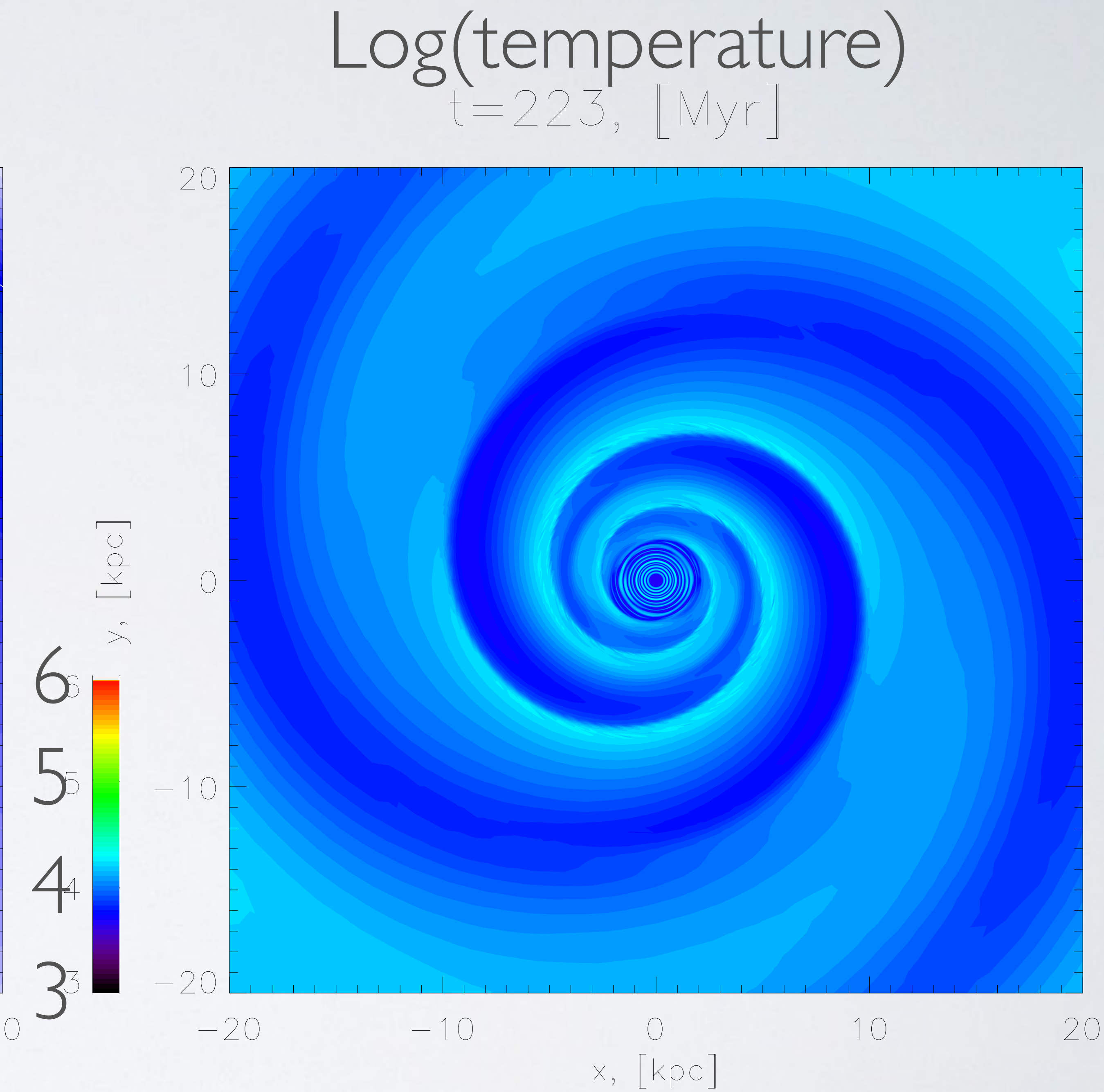


Log(temperature)



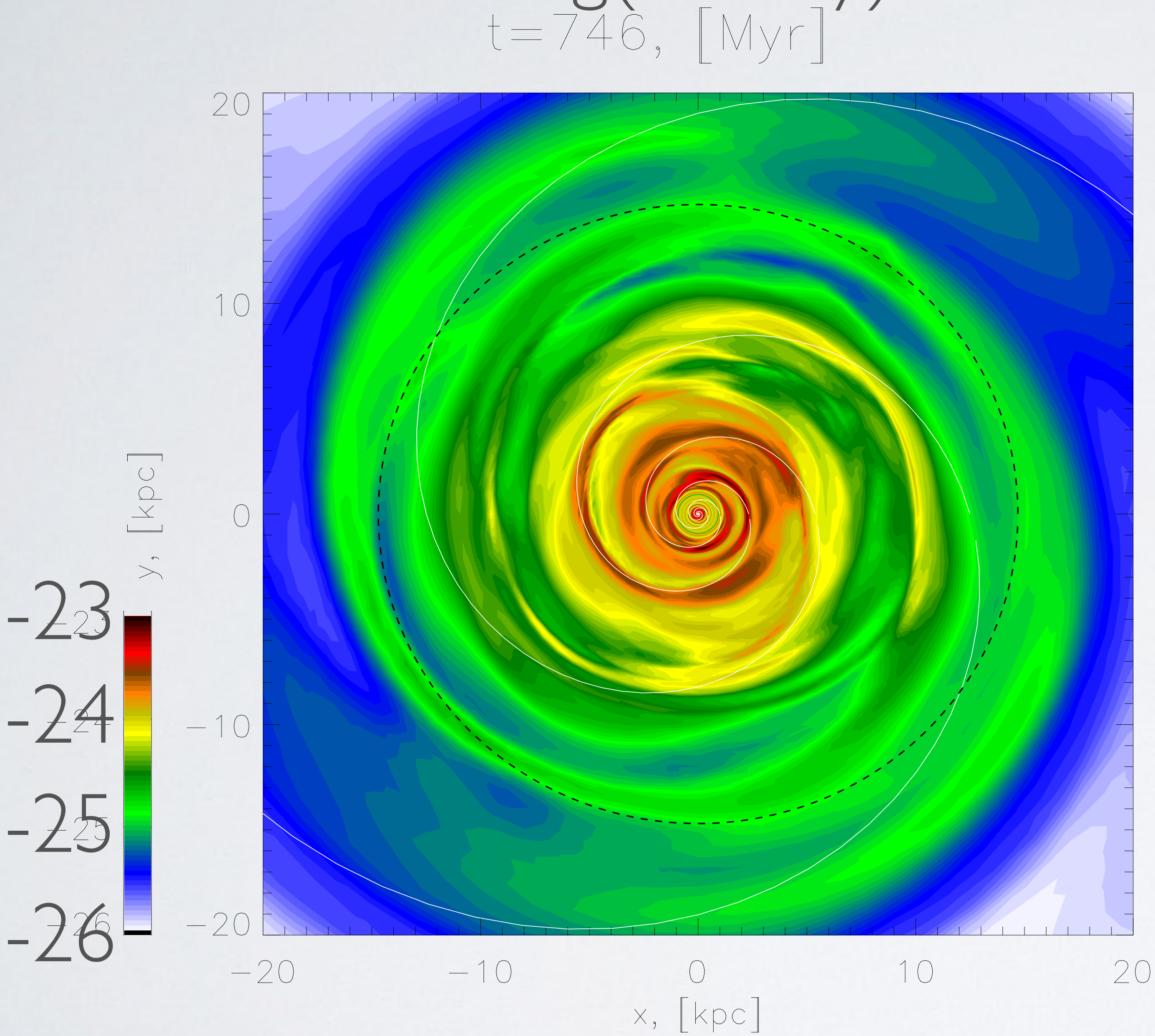
Results(t=220Myr)



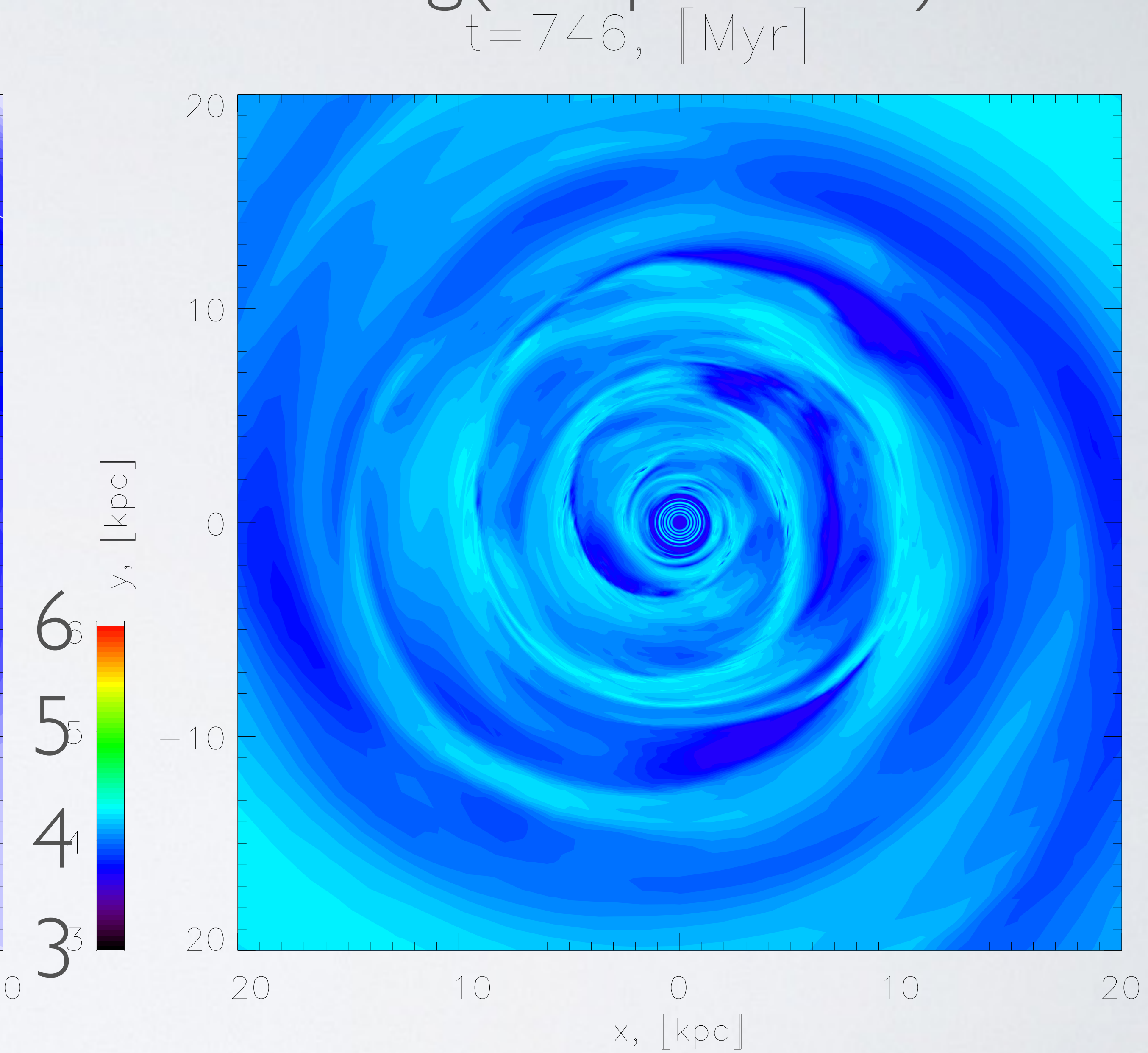


Results(t=750Myr)

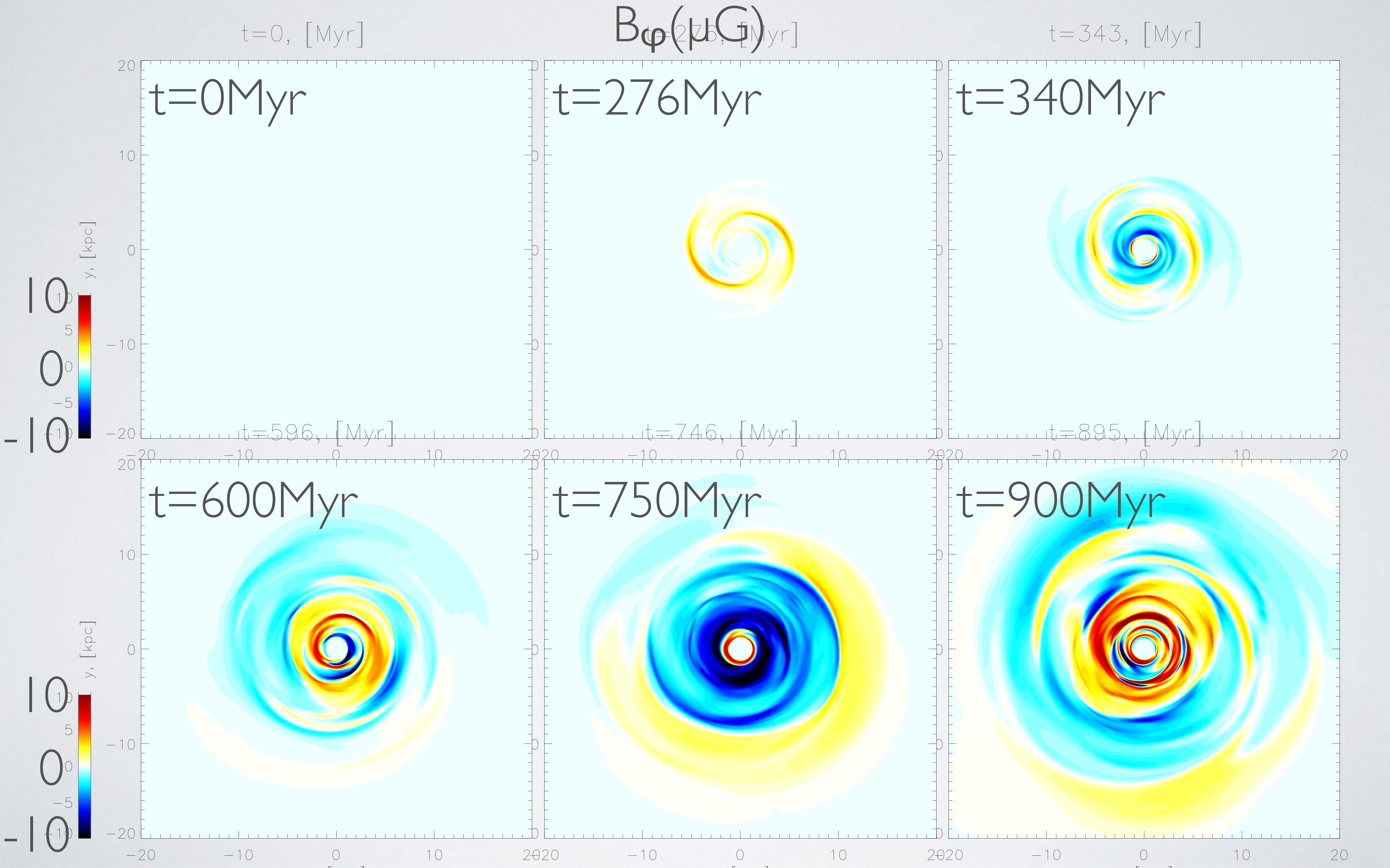
Log(density)



Log(temperature)

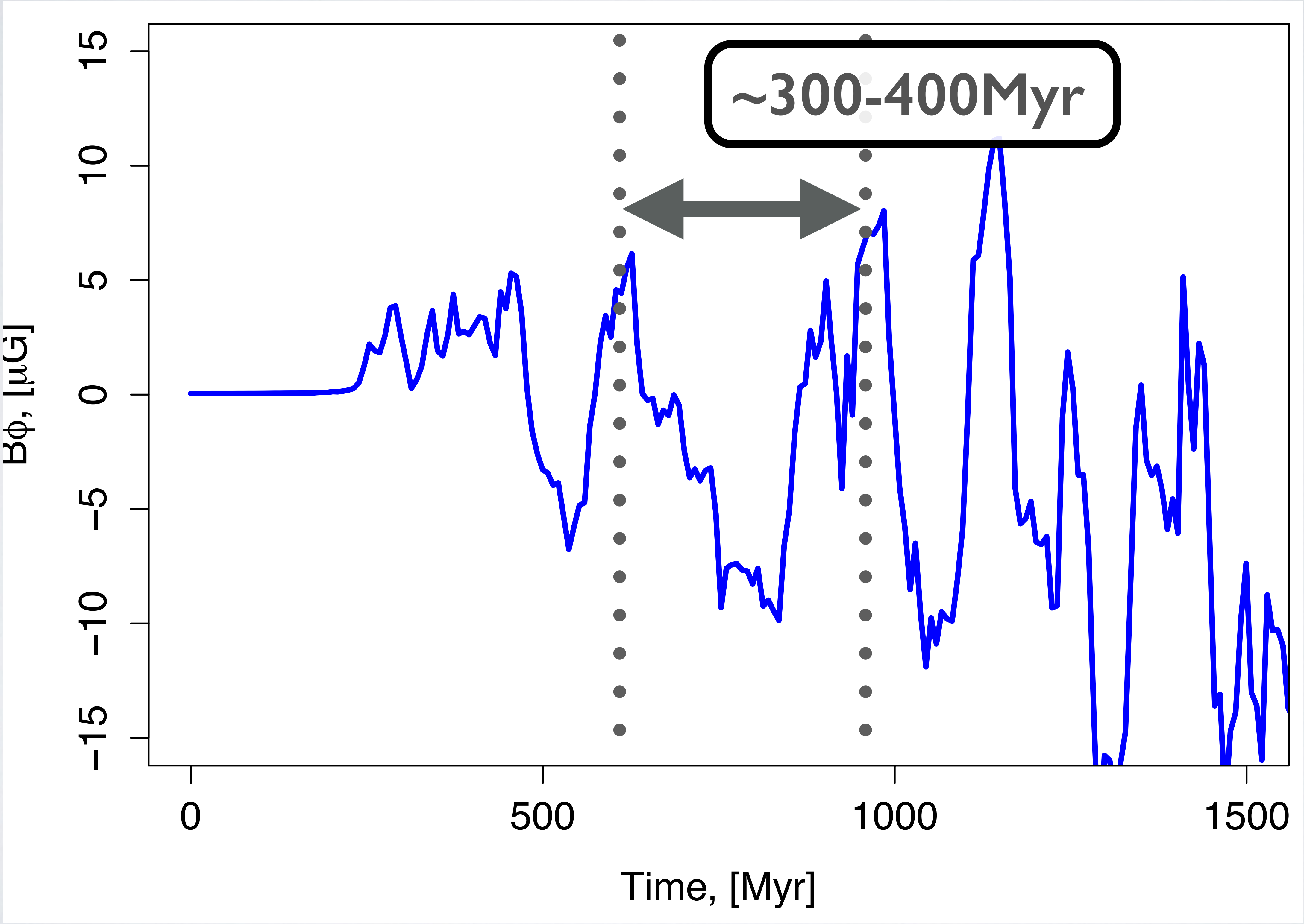


Results

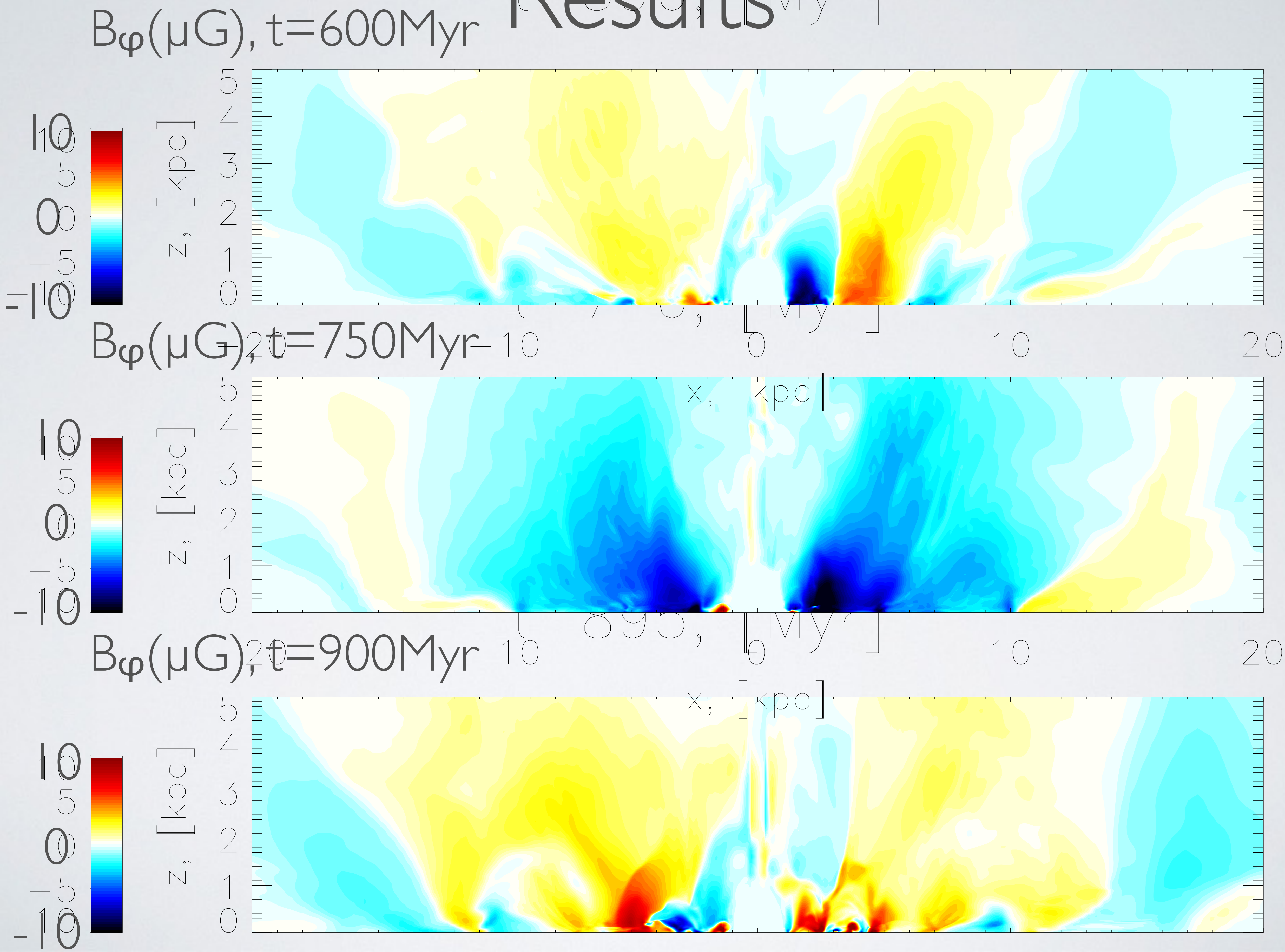


$B_\varphi(\mu G)$
t=0Myr
t=276Myr
t=340Myr
t=600Myr
t=750Myr
t=900Myr
10
0
-10
10
0
-10

Time Evolution of B$\boldsymbol{\varphi}$(R=5kpc)

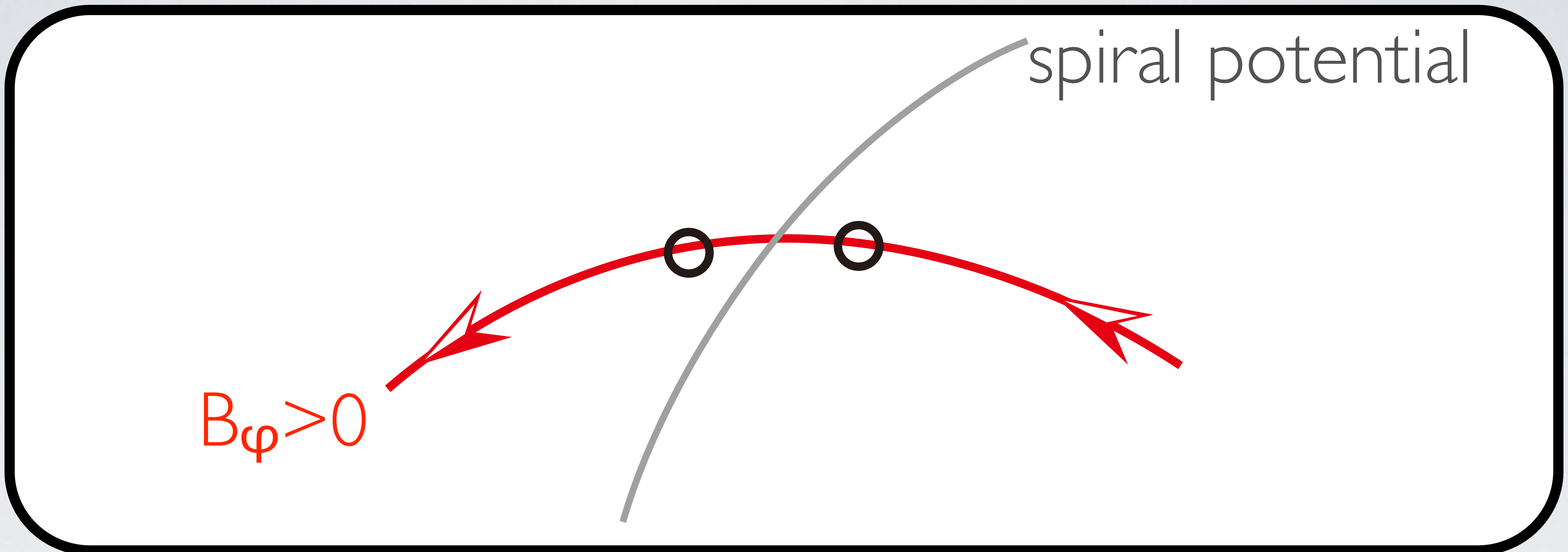


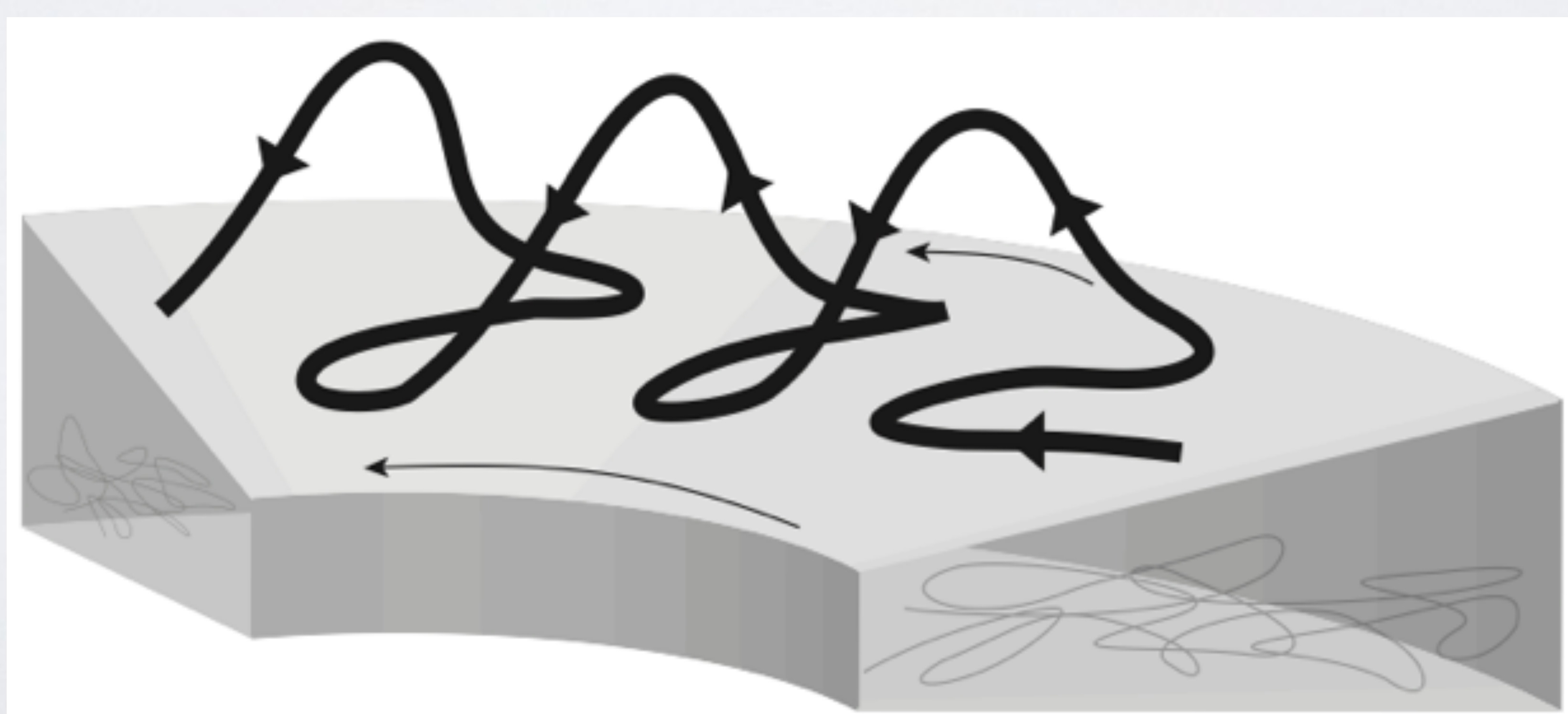
Results



$B_\varphi(\mu G)$, t=600Myr
$B_\varphi(\mu G)$, t=750Myr
$B_\varphi(\mu G)$, t=900Myr
10
0
-10
z, [kpc]
x, [kpc]

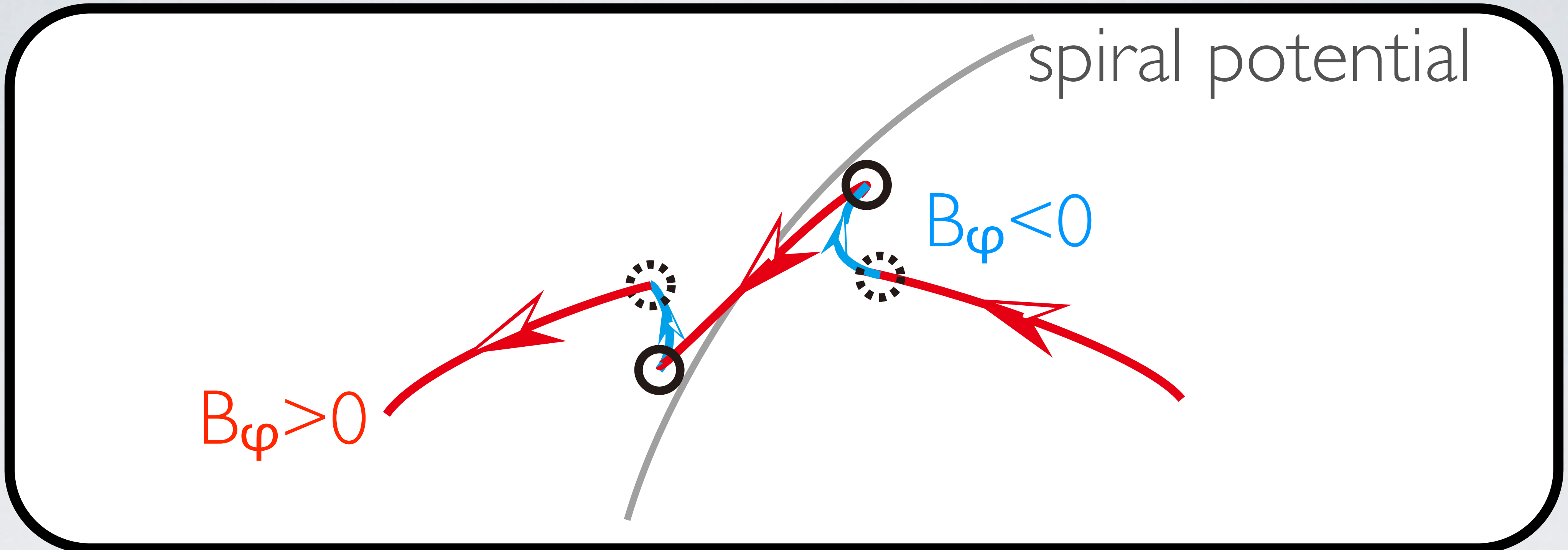
B-field Reversals Induced by Spiral Arms

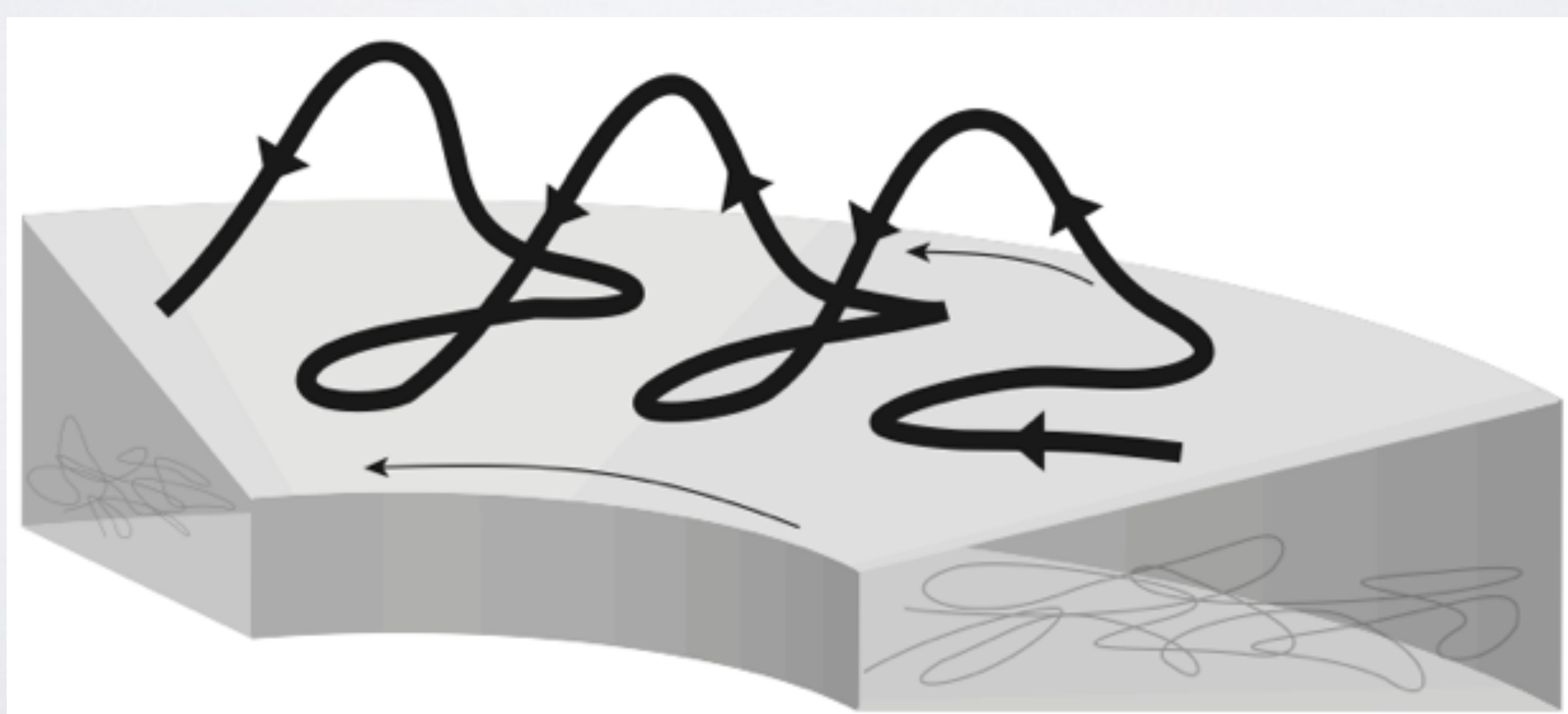




Nishikori+ 2006
Machida+ 2013

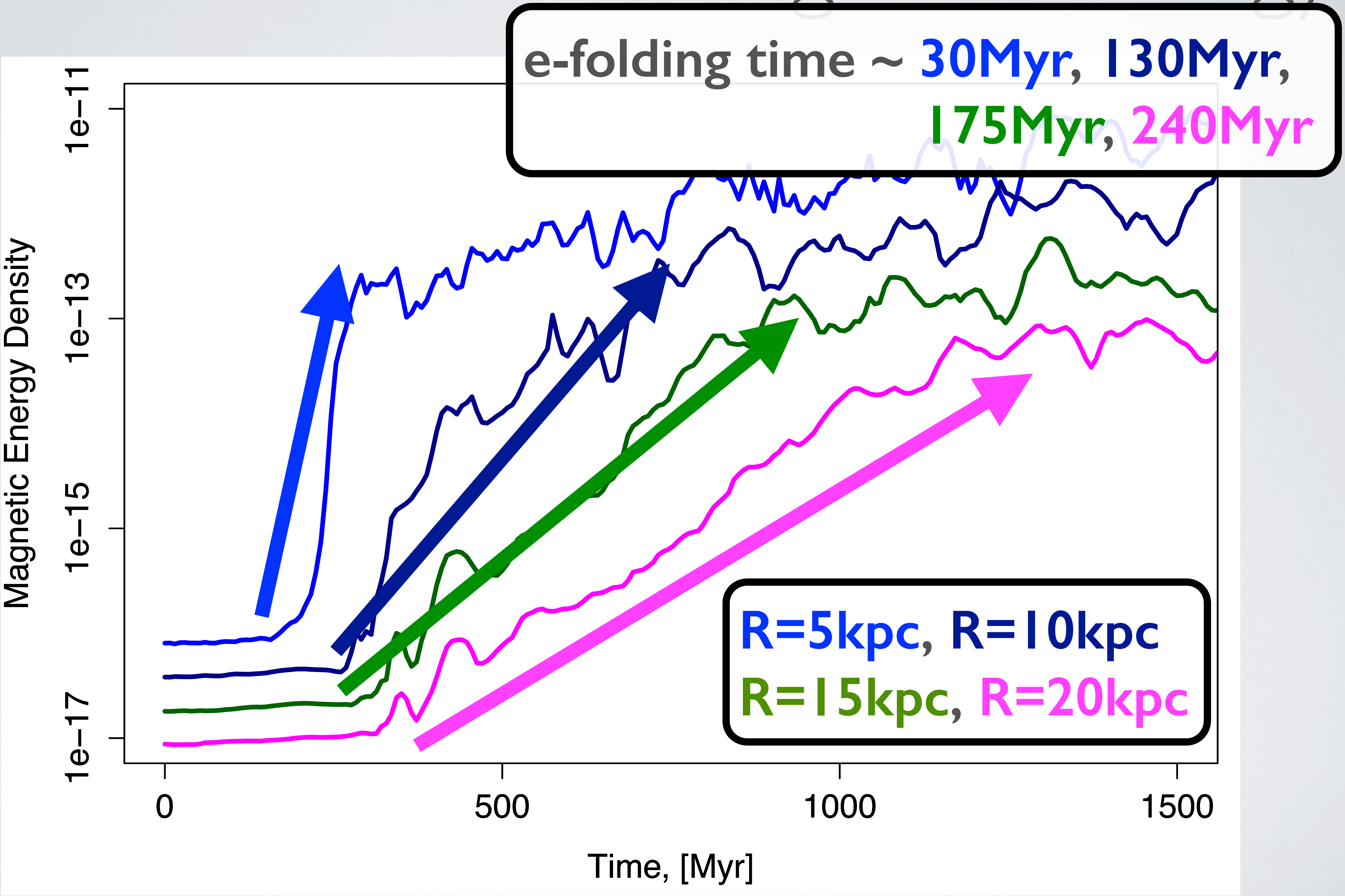
B-field Reversals Induced by Spiral Arms



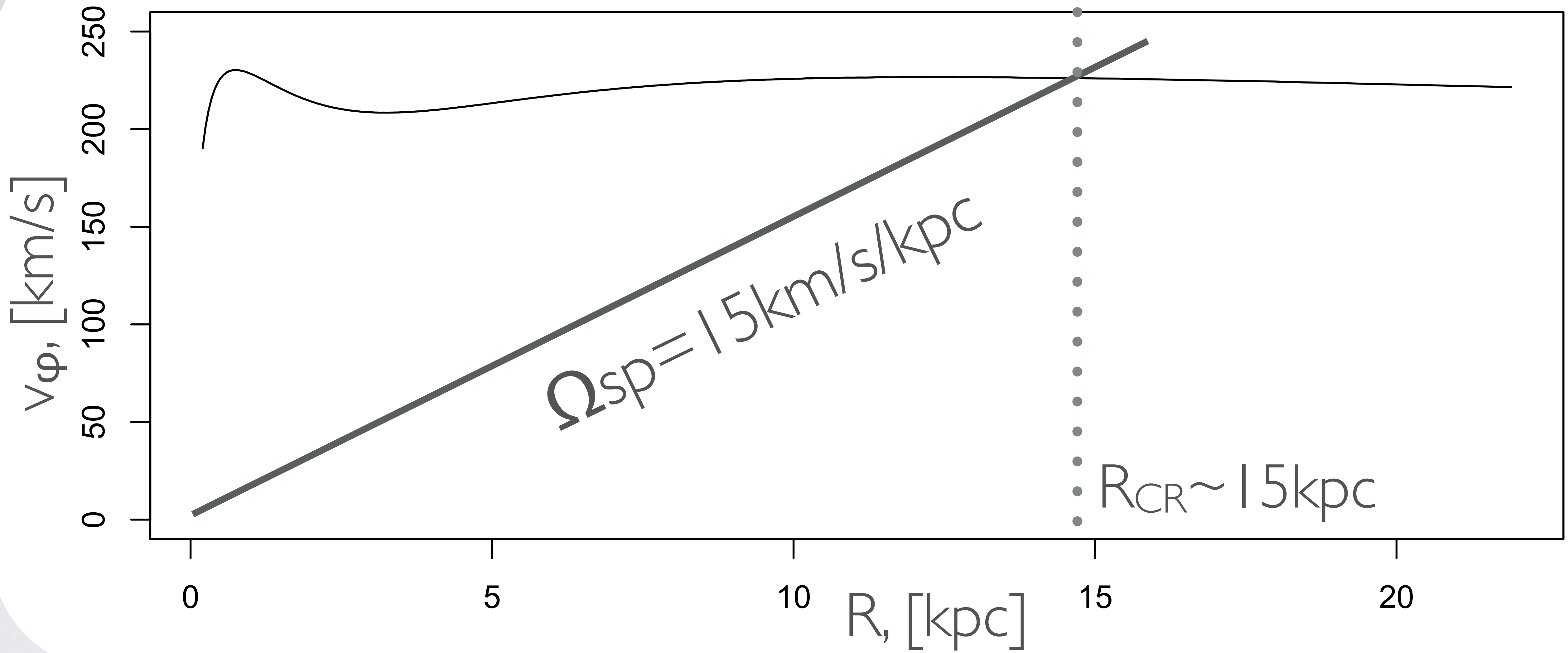


Nishikori+, 2006
Machida+, 2013

Time Evolution of Magnetic Energy



Effects of Spiral Pattern Speed



内側ほど磁場が増幅==>内側ほど渦状腕を頻繁に通過

==>磁場増幅のタイムスケールはΩ_{sp}に依存？

Concluding Remarks

Concluding Remarks

渦巻き銀河を意識した3次元MHD simulationの結果・・・

1. 磁気流体的銀河衝撃波が形成

 ==>**劇的な磁場増幅** $t_{evolution} << t_{dyn}$

2. 磁気流体銀河衝撃波＋磁気浮力不安定性

 ==>**磁場の頻繁な反転, ハロー部の磁化**

3. 磁場の増幅率

 ==>**Ωspに依存する**可能性あり(今後シミュレーション予定)

Thank you
for your attention