Global Galactic Dynamo Driven by Cosmic Rays and Exploding Magnetized Stars

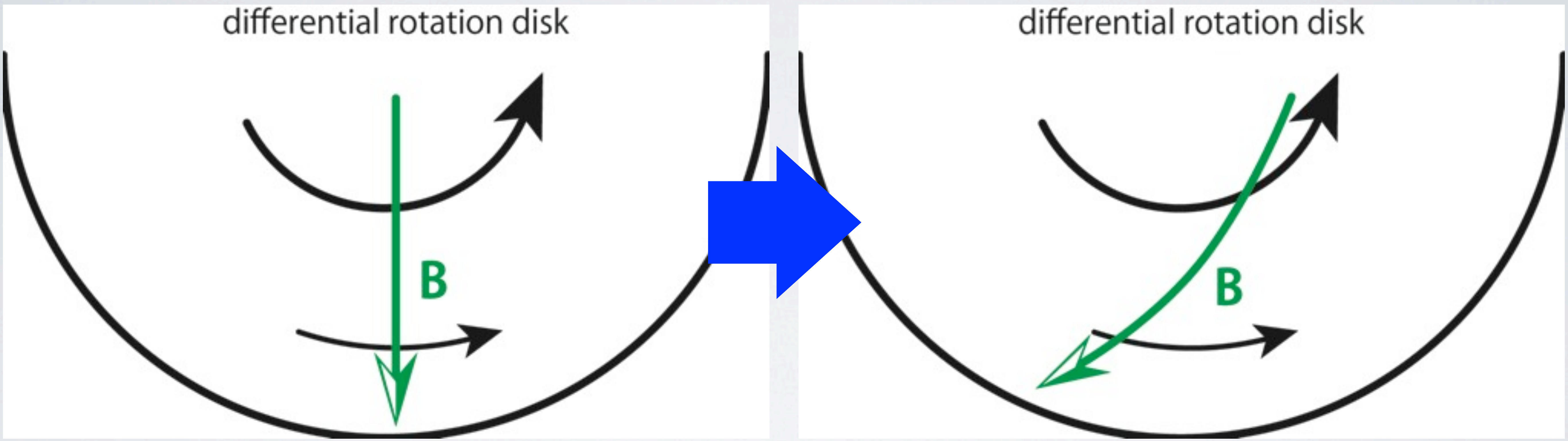
Hanasz, Woltanski & Kowalik, 2009

第139回雑誌会 (2012 Oct. 24)

中村翔(服部研 1st year Ph.D)

What is Dynamo ?

『流体の運動』から『磁場』を作り出す機構。



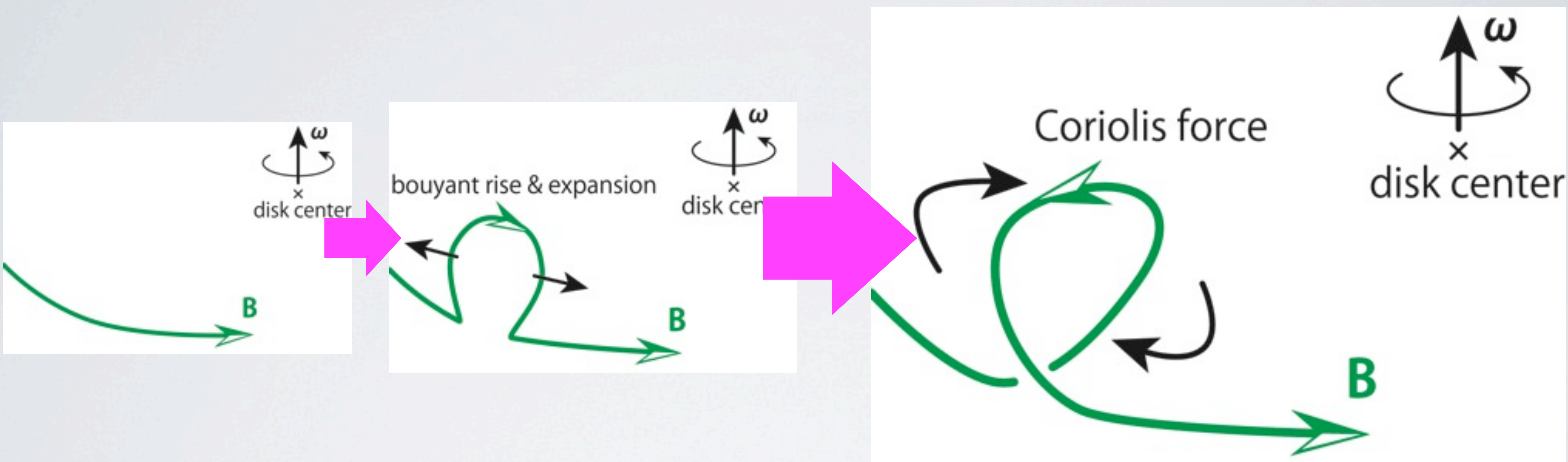
差動回転により、B_rからB_φを生成 ===> ω-dynamo

磁力線のストレッチ===>磁場の増幅

方位角方向に磁場をそろえる効果

What is Dynamo ?

『流体の運動』から『磁場』を作り出す機構。



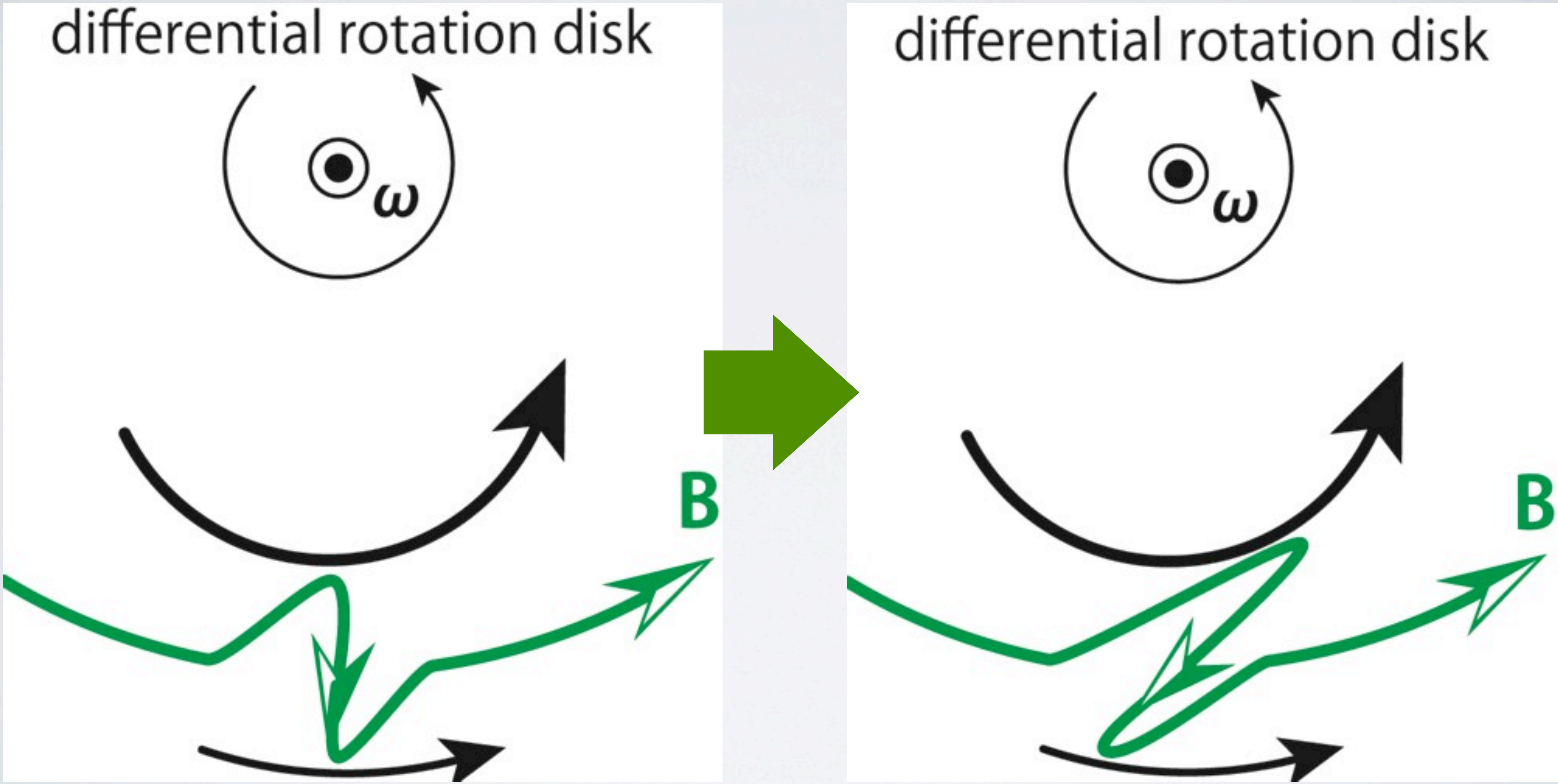
コリオリ力により、B_φからB_rを生成 ===> α-dynamo

磁力線のストレッチ===>磁場の増幅

動径方向に磁場をそろえる効果

What is Dynamo ?

『流体の運動』から『磁場』を作り出す機構。

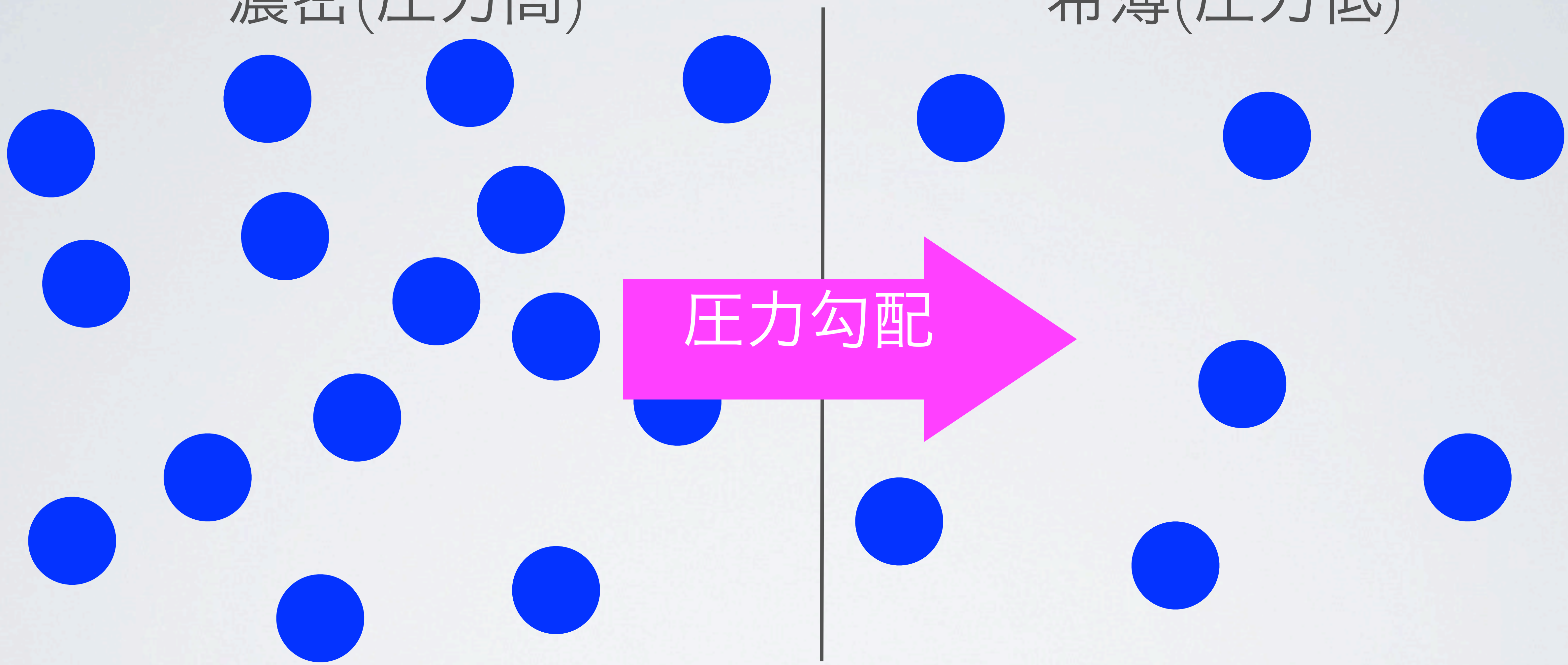


ω-dynamo, α-dynamoの複合技 ===> αω-dynamo

Cosmic Rayの効果

普通の流体の中にCosmic Rayの塊みたいなものを想像。

濃密(圧力高)　　希薄(圧力低)

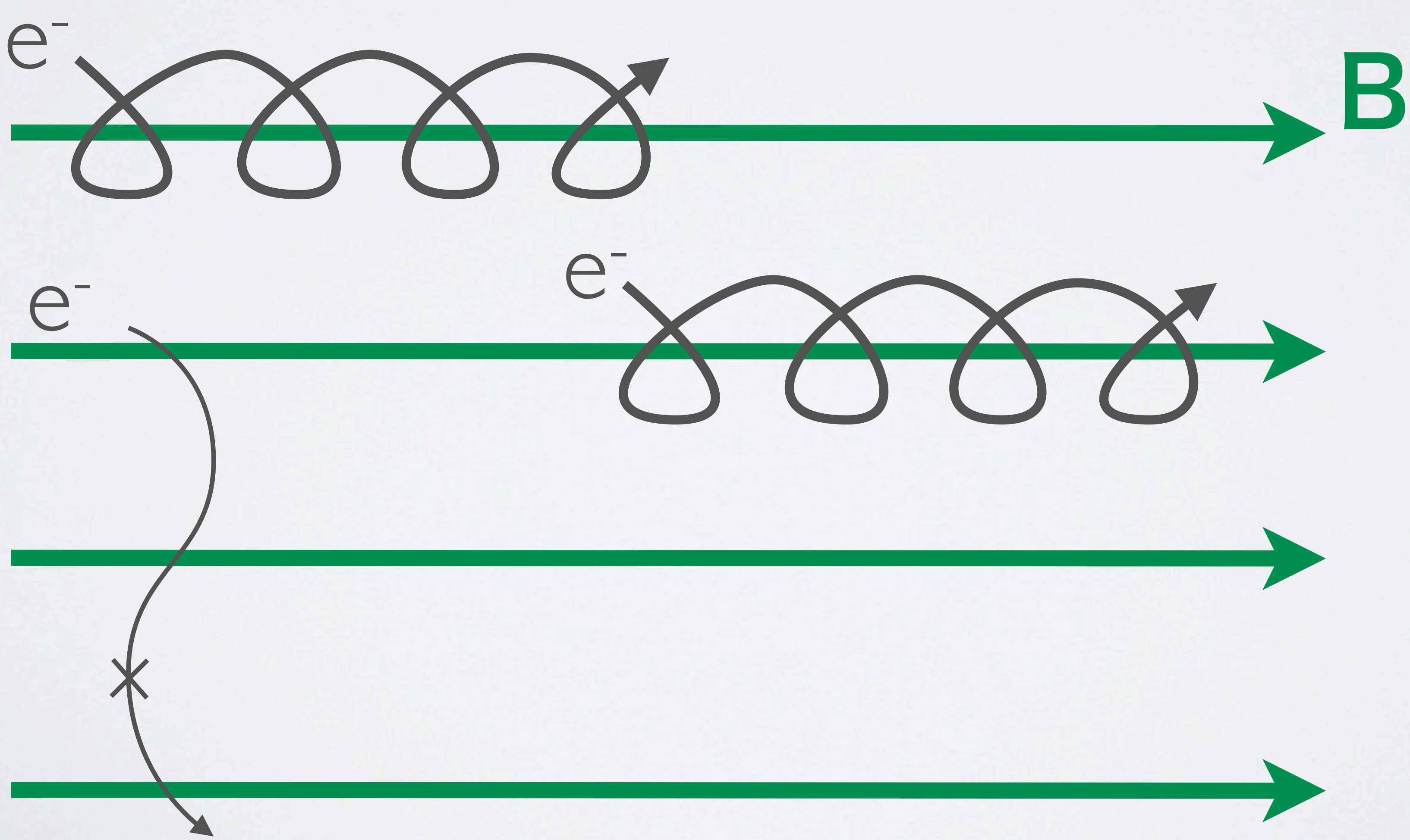


青丸:Cosmic Ray

流体力学と同じ考え方で、圧力の高い方から低い方へ流体に力がはたらく ===> Cosmic Ray pressure

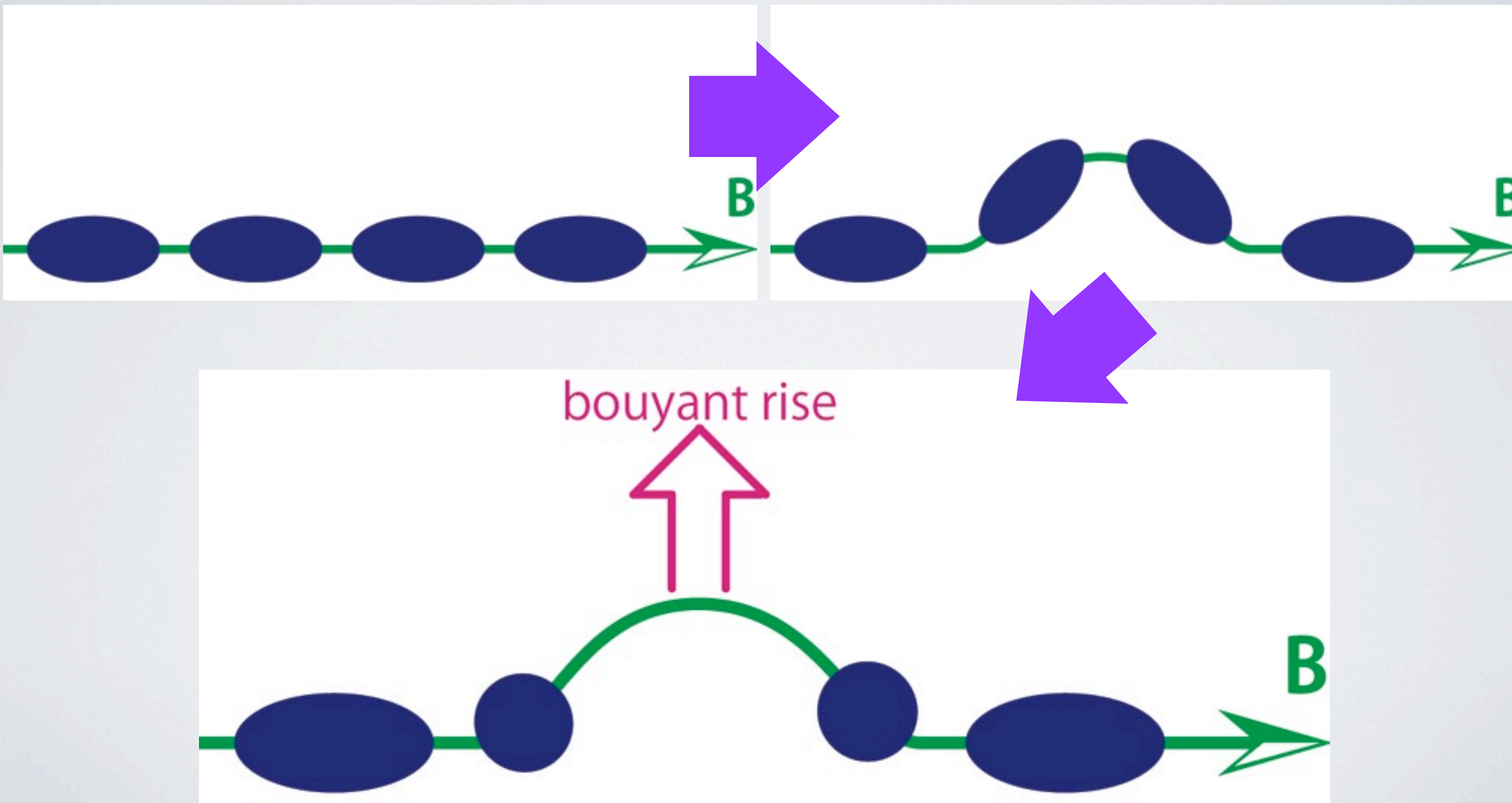
Cosmic Rayの拡散

Cosmic Ray = おもに相対論的な電子。電荷を持っているので磁場に平行方向には素早く移動。



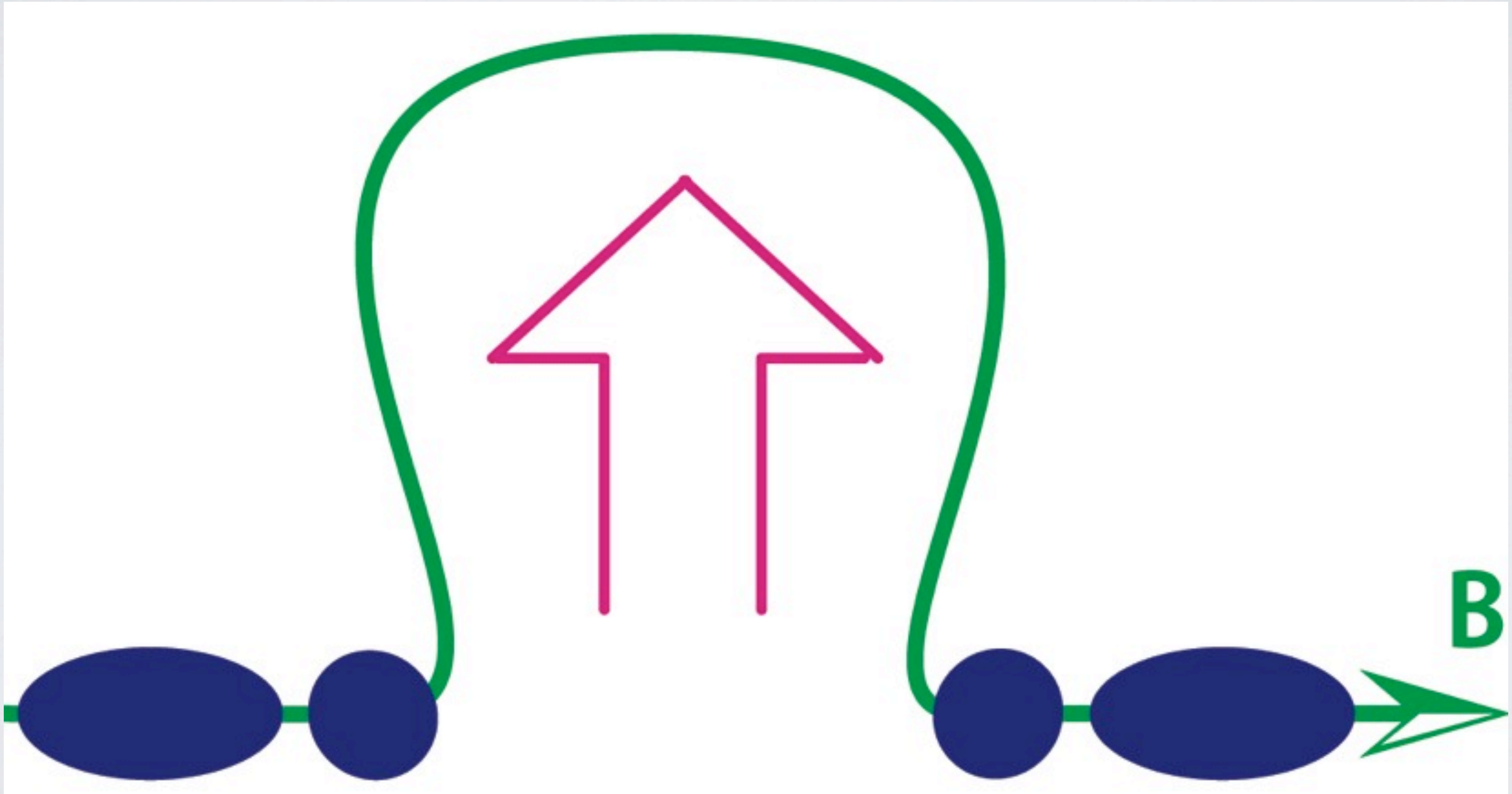
What is CR drivenDynamo ?

通常の場合 (Parker Instability)。



What is CR drivenDynamo ?

Cosmic Rayは普通の流体より素早く落ちる。磁力線が浮力で膨らむスピードが早くなる。



磁力線のストレッチも強力===>磁場の増幅大

Numerical Set up

①初期はCRはなし、SourceとしてSNR.

SNによる星間空間へのエネルギー放出=10^{51}erg、そのうち10%がCosmic Rayのエネルギーとして注入

②初期は磁場なし、SNからのエネルギー放出のうち10%を磁場のエネルギーとして注入。

③磁気拡散は全領域一様一定

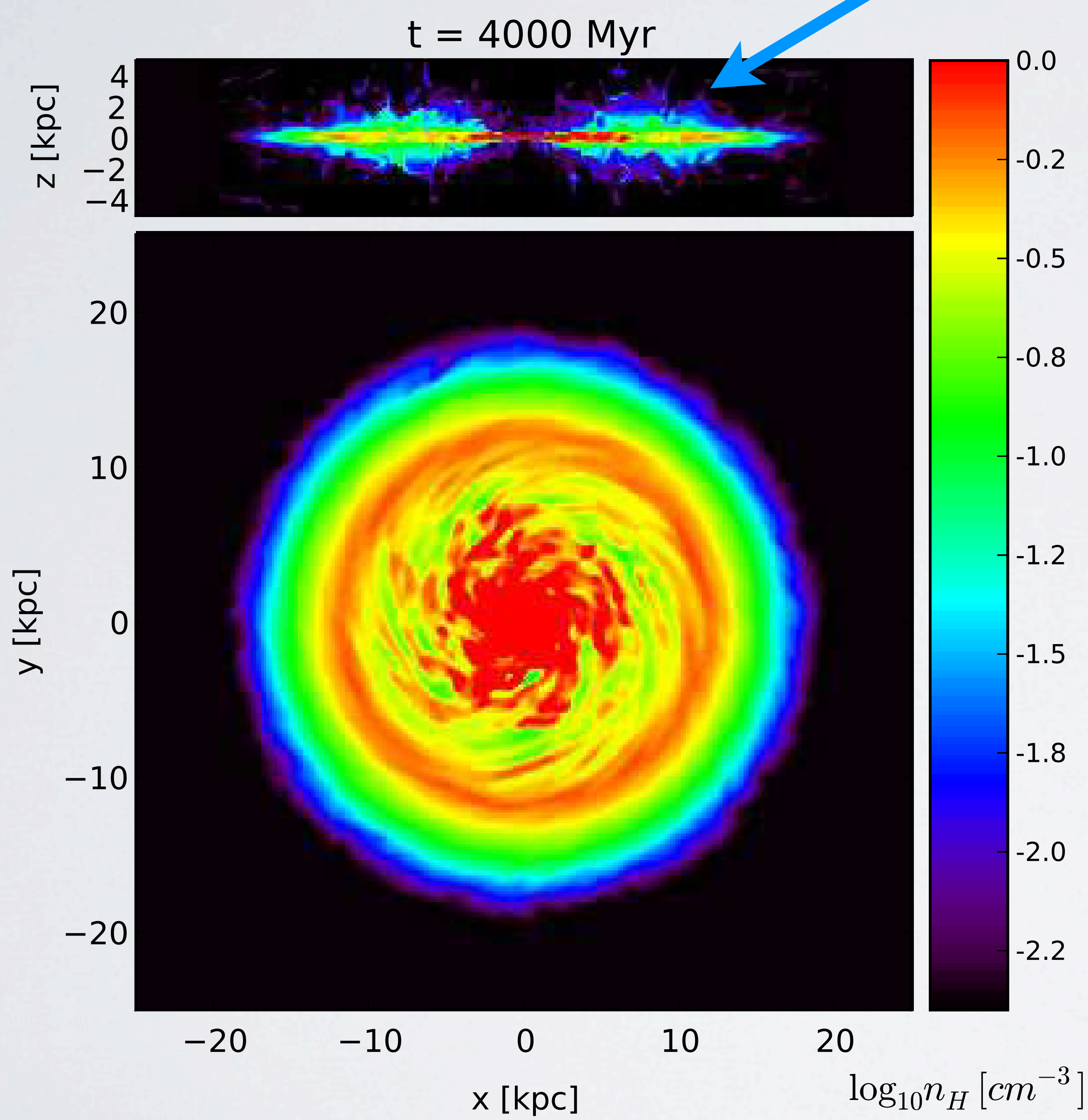
④軸対称ポテンシャルはAllen&Santillan 1991,
　初期ガス分布はFerriere 1998

⑤SNの発生確率もこのガス分布から算出、発生確率固定、1Gyrまで注入する。

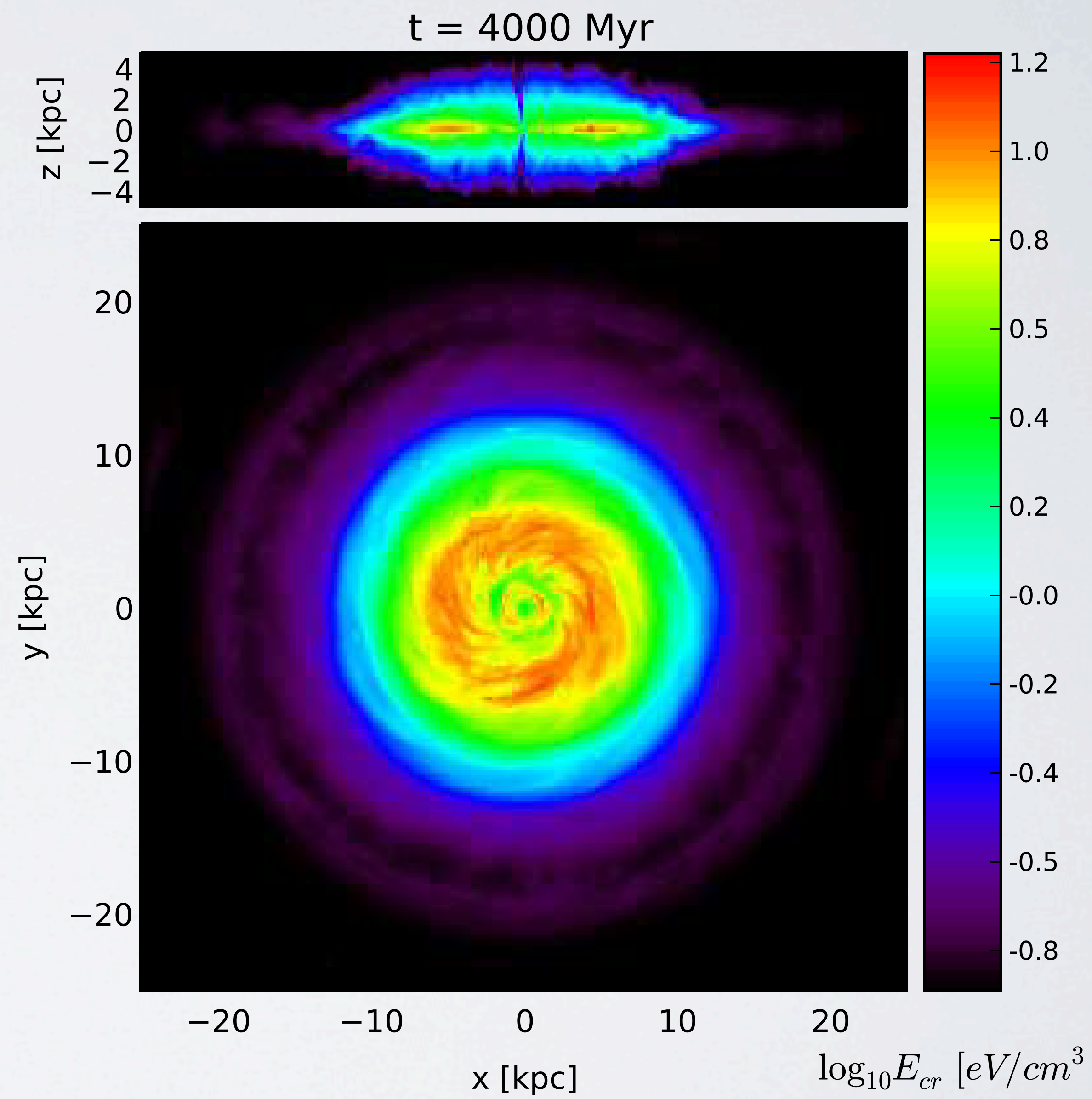
⑥simulation region:-25kpc$<x, y<25$kpc, -5kpc$<z<5$kpc

Results:structure of ISM

vertical wind speed ~ 100 kms^{-1}, $1M_{\odot}yr^{-1}$

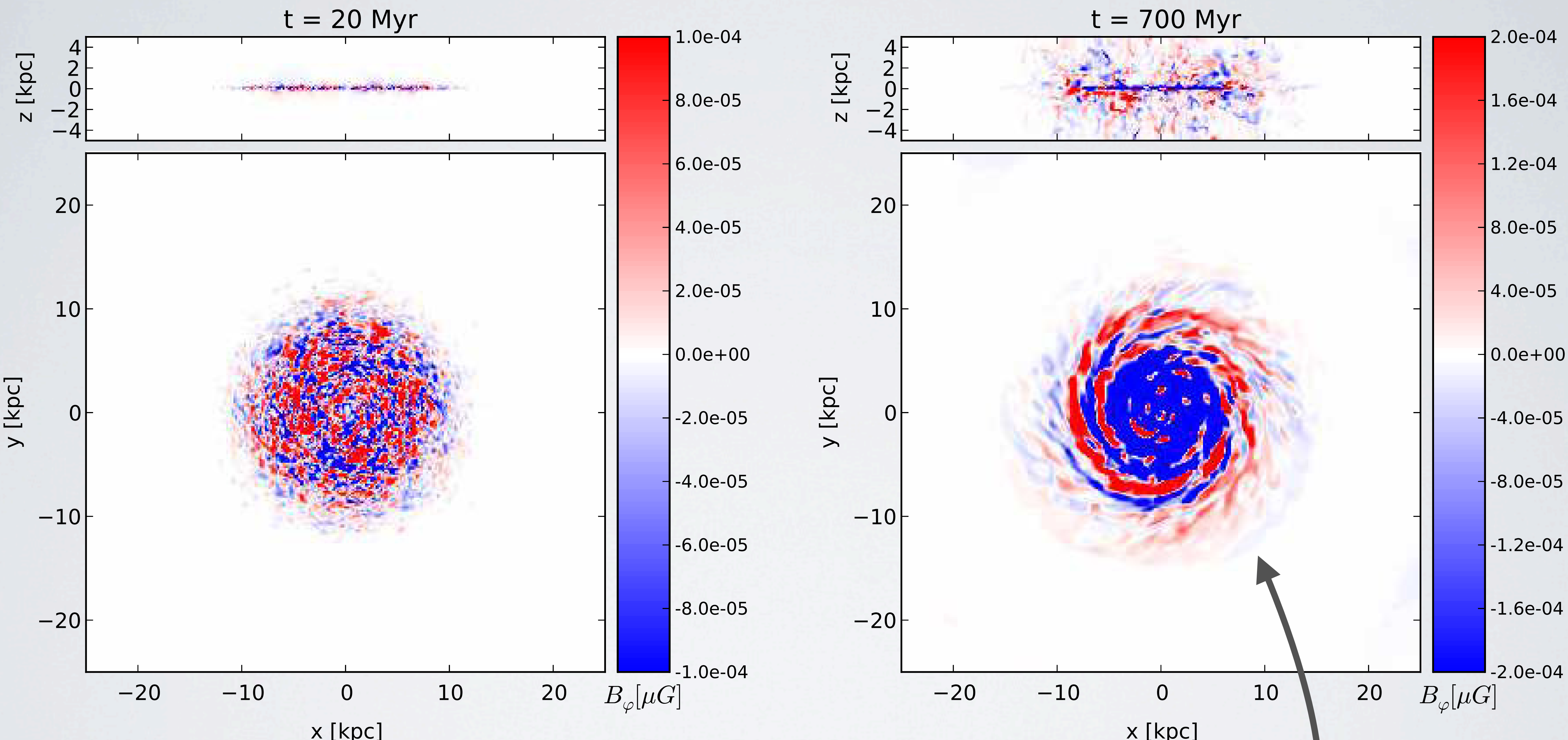


color:gas number density



color: Cosmic Ray energy

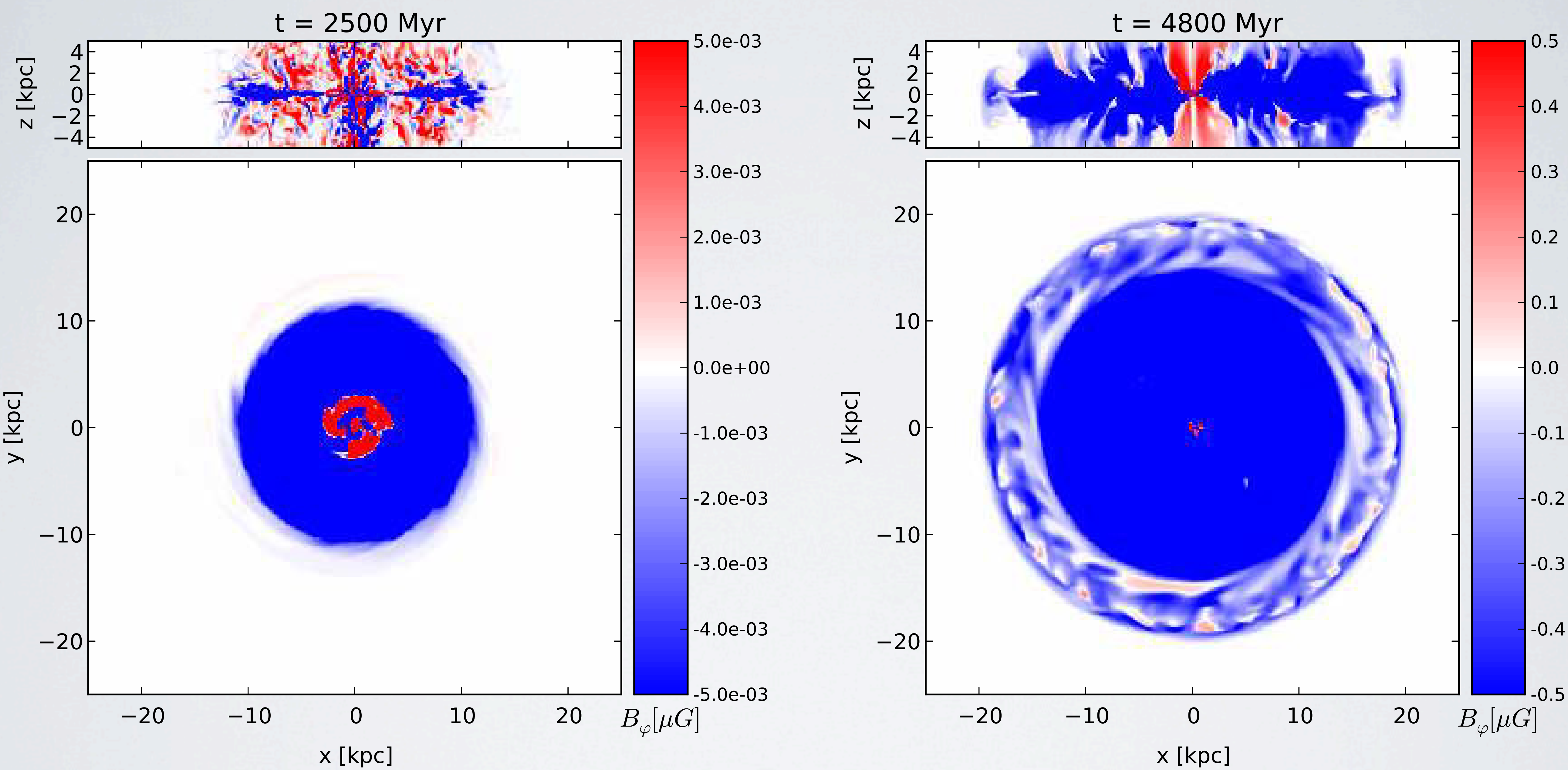
Results:structure of B_φ



color:toroidal magnetic field

わりと初期:磁場の反転が多い

Results:structure of B_φ

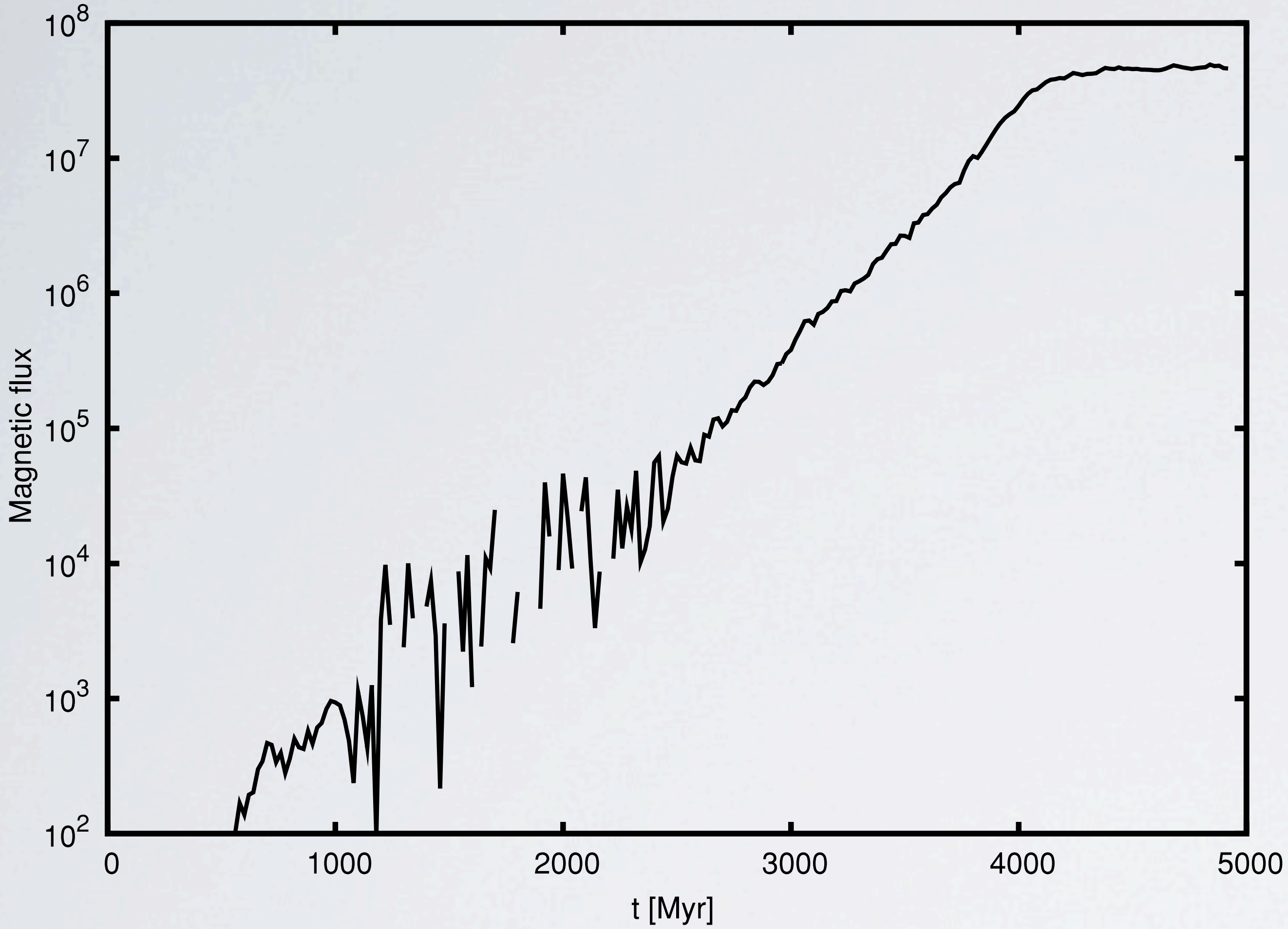


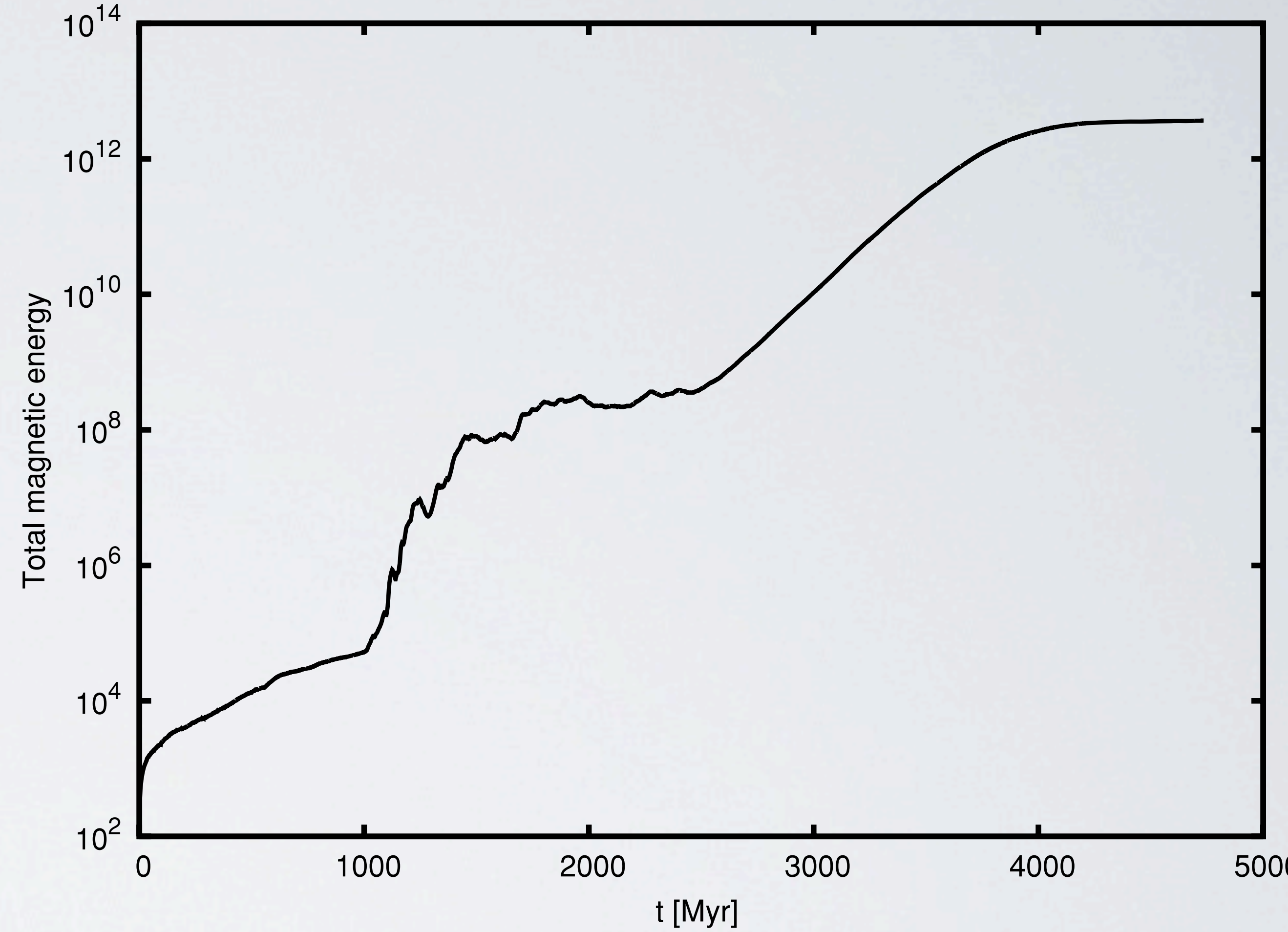
color:toroidal magnetic field

中盤, 終盤:磁場の方向が一定

(+の場所はずっと+、-の場所はずっと-)

Results:magnetic flux, energy growth





line:magnetic flux

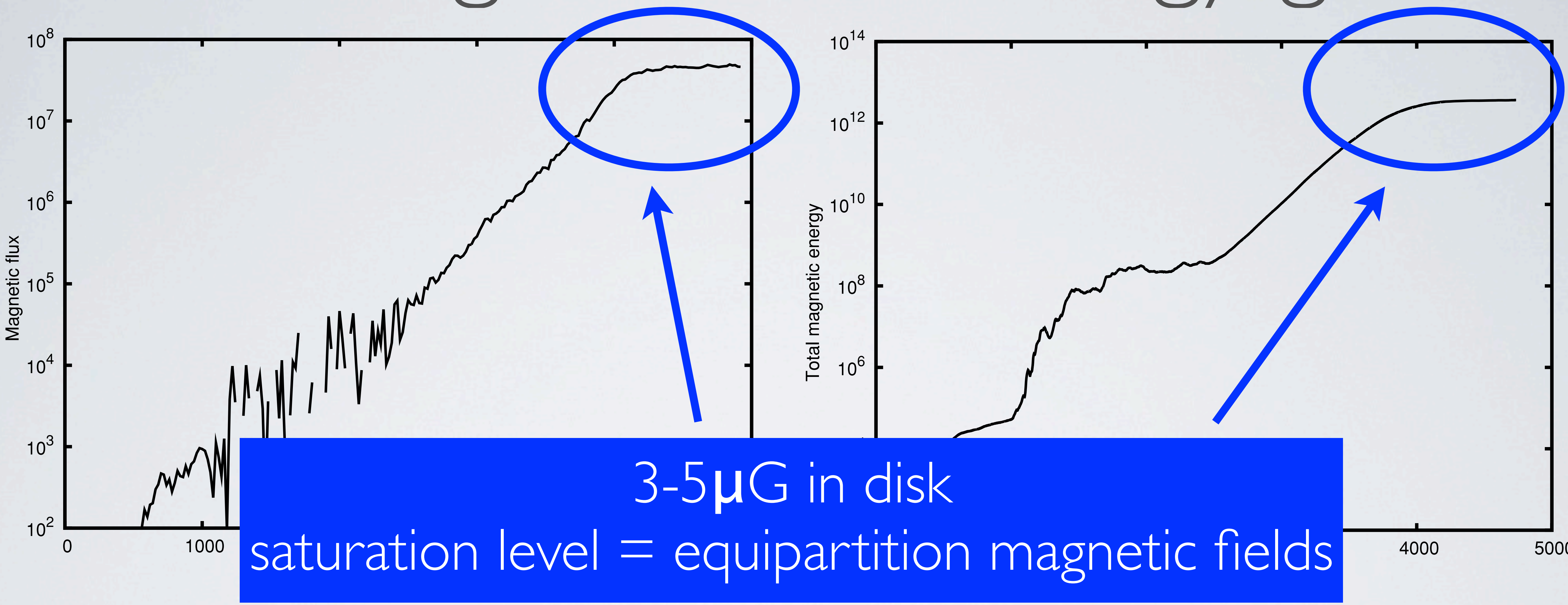
line:magnetic energy

t=0-2.3Gyr, magnetic flux changes sign

t>2.5Gyr, exponential curve

e-folding time ~ 270Myr

Results:magnetic flux, energy growth



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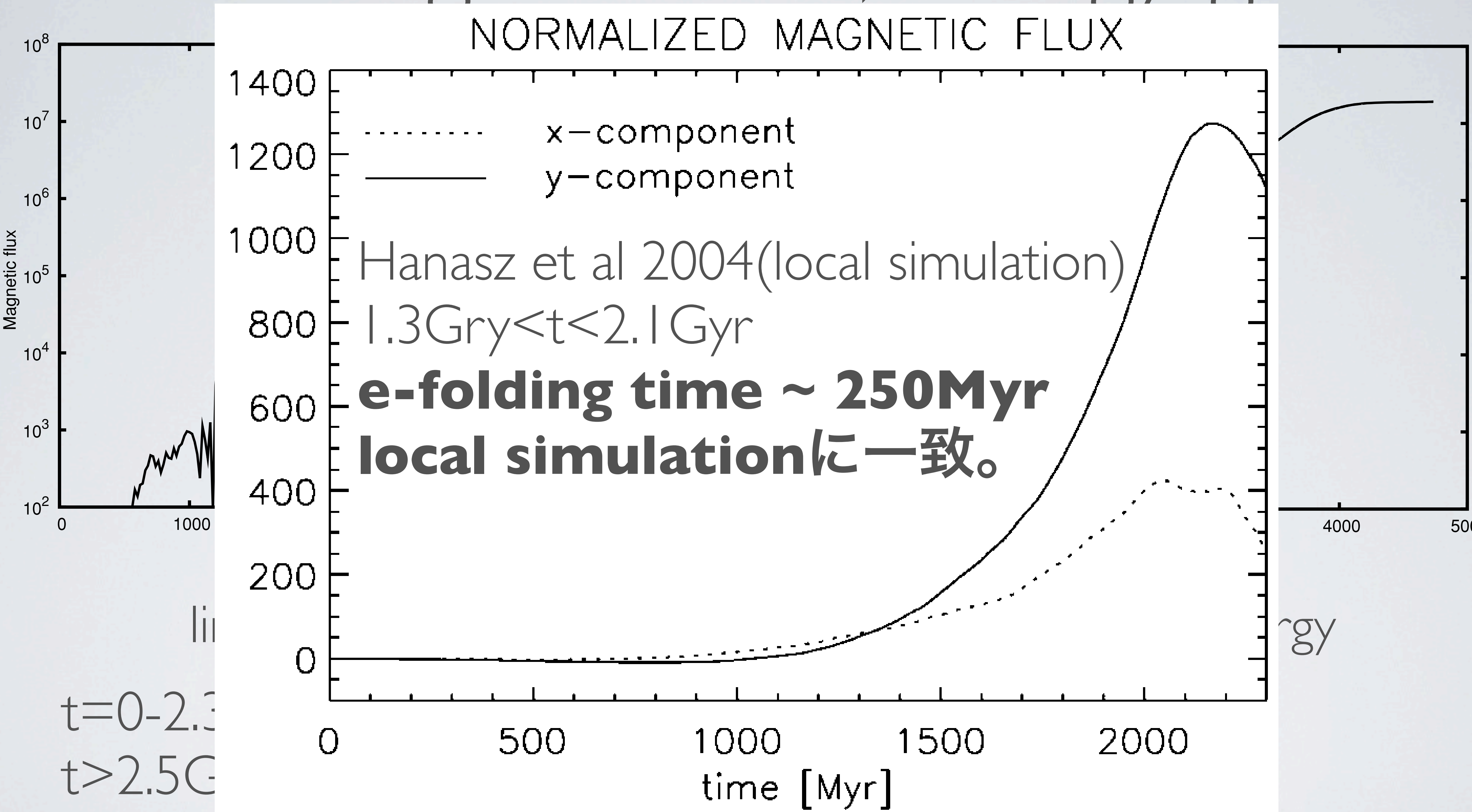


Hanasz et al 2004(local simulation)

1.3Gry<t<2.1Gyr

e-folding time ~ 250Myr

local simulationに一致。

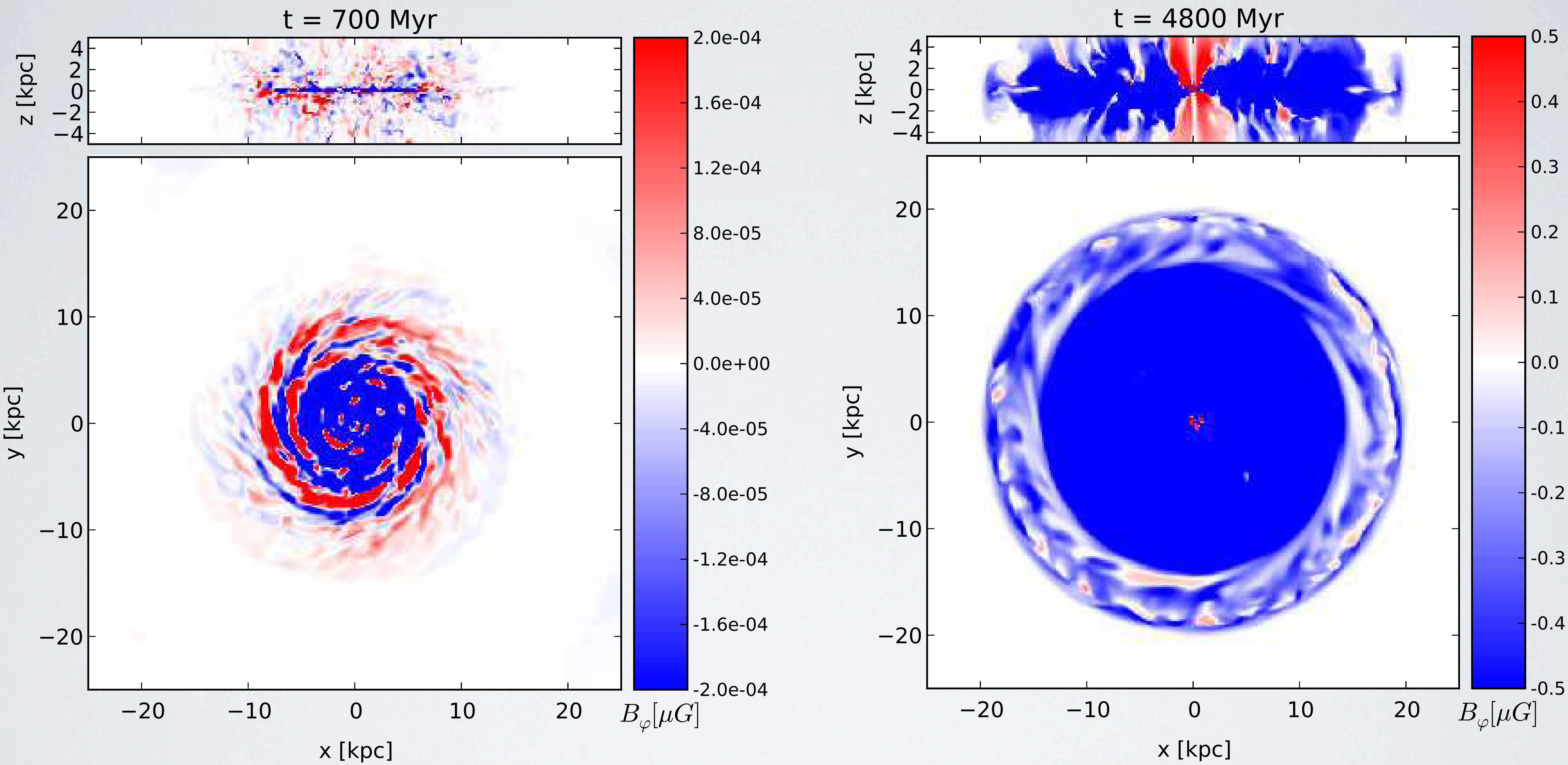
li… …rgy

t=0-2.3…

t>2.5G…

e-folding time ~ 270Myr

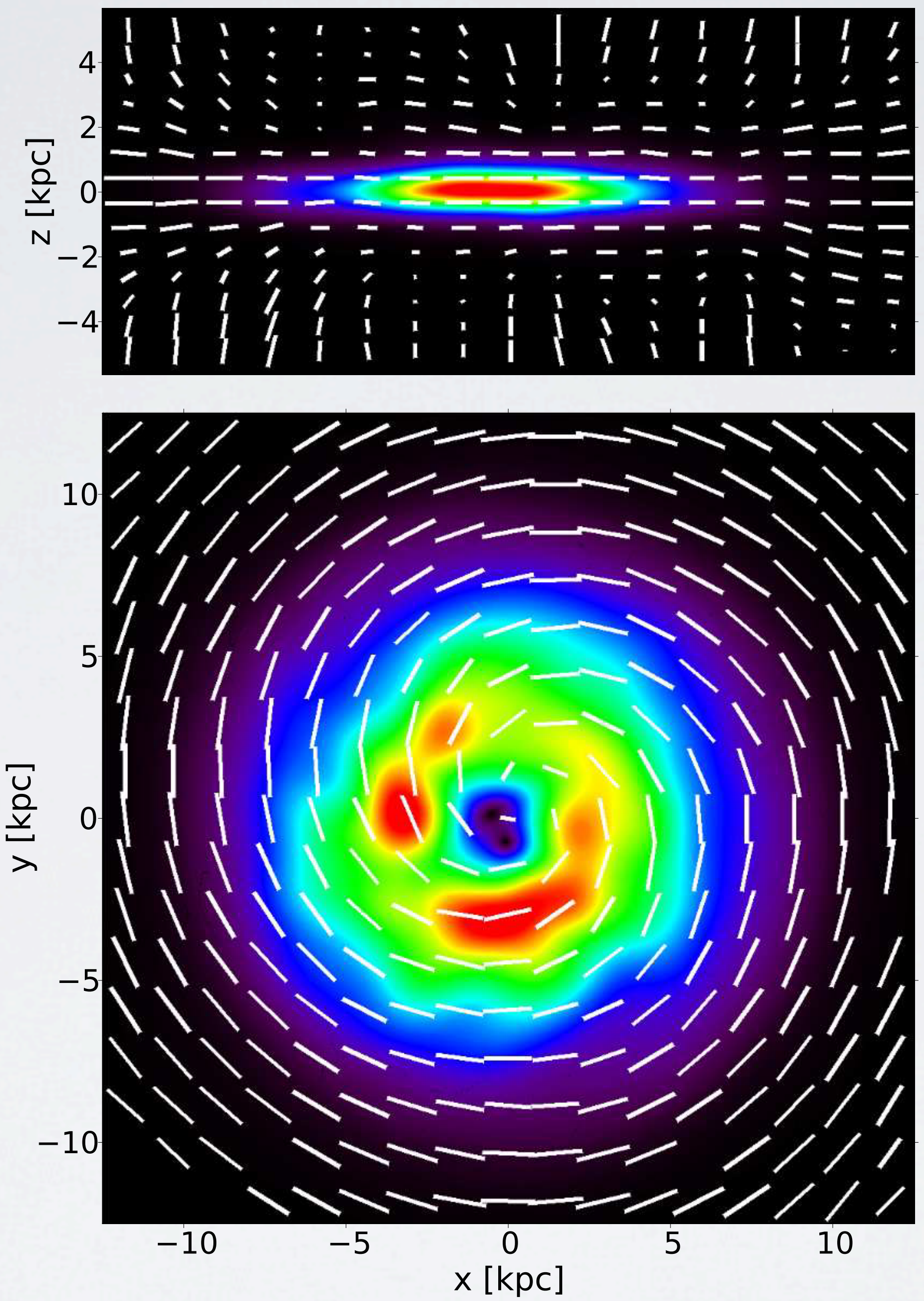
Results:CR diffusivity



color:toroidal magnetic field

CRの磁場に平行方向の拡散を小さくすると、数Gyr経過しても左図くらい反転が残る(らしい)。

Results:virtual radio observations



color:polarized intensity of synchrotron emission(t=4.8Gyr)
line:electric vectors rotated by 90°(magnetic field line)

λ=3.6cm(8.35GHz) observations

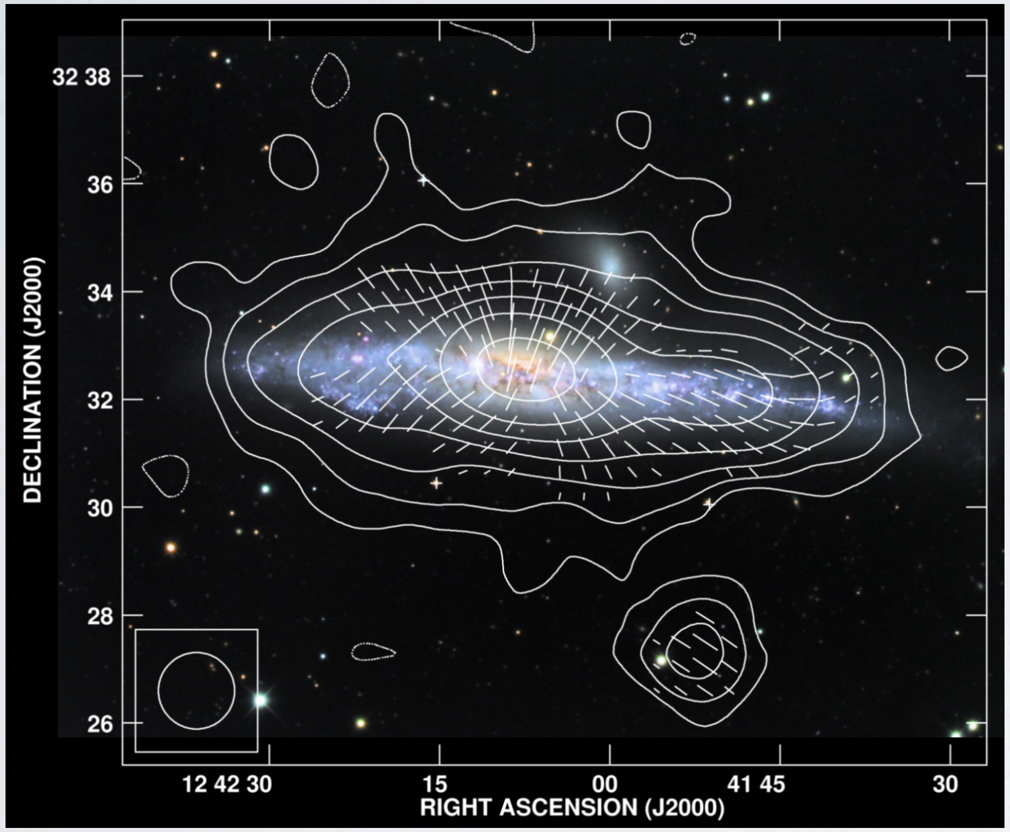


Fig. 3. Radio continuum emission of the edge-on spiral galaxy NGC 4631 at λ3.6cm (8.35 GHz) with the 100 m Effelsberg telescope with 84″ $HPBW$. The contours in give the total intensities, the vectors the intrinsic magnetic field orientation. The radio map is overlayed on an optical image of NGC 4631 taken with the Misti Mountain Observatory (Copyright: MPIfR Bonn).

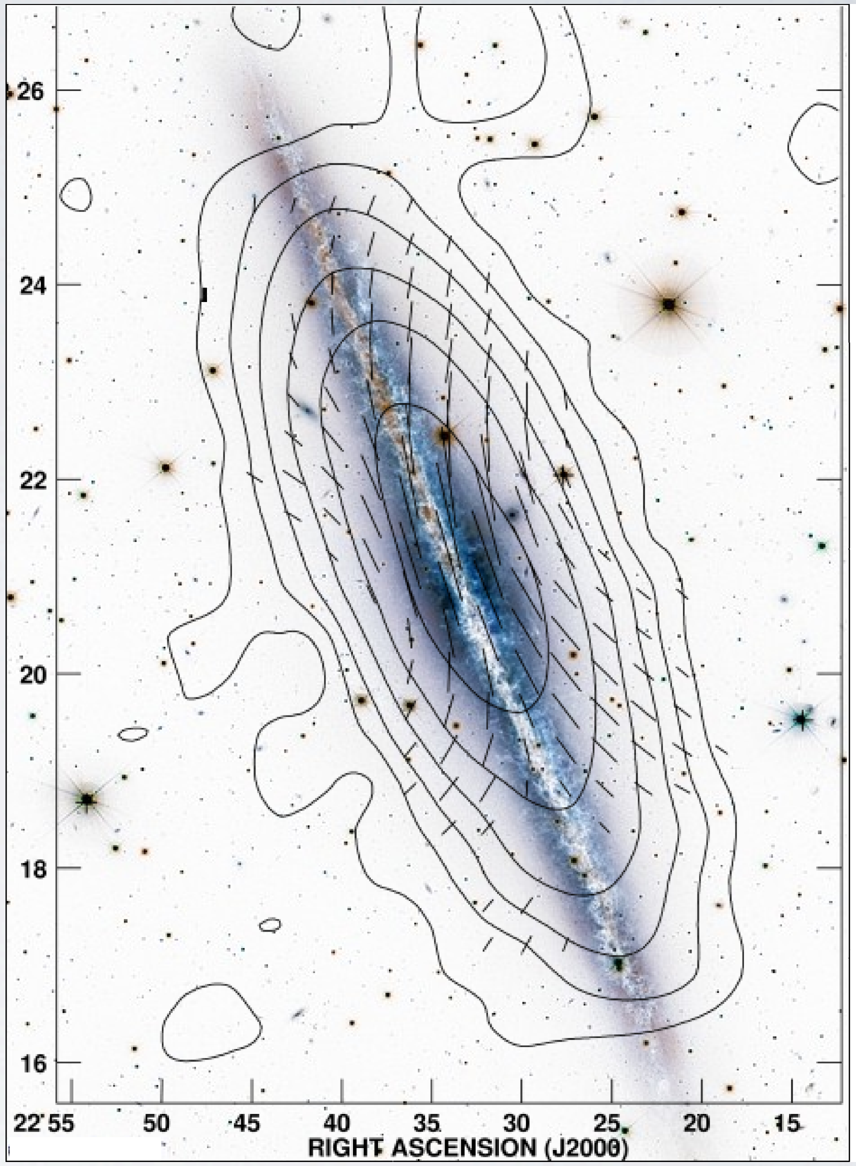
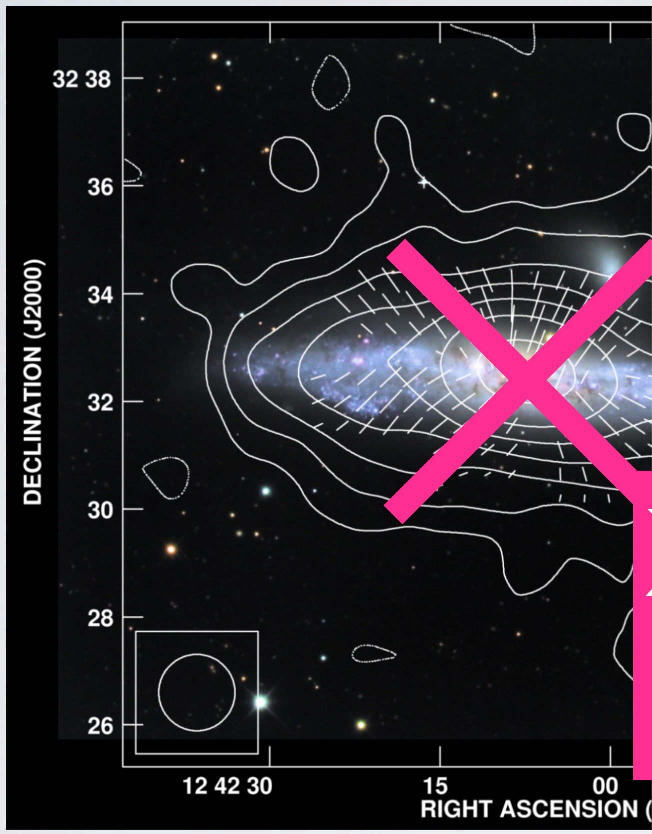


Fig. 1. Radio continuum emission of the edge-on spiral galaxy NGC 891 at λ3.6cm (8.35 GHz) with the 100 m Effelsberg telescope with a resolution of 84″ $HPBW$. The contours give the total intensities, the vectors the intrinsic magnetic field orientation (Copyright: MPIfR Bonn). The radio map is overlayed on an optical image of NGC 891 from the Canada-France-Hawaii Telescope/(c)1999 CFHT/Coelum.

Krause 2009

λ=3.6cm(8.35GHz) observations



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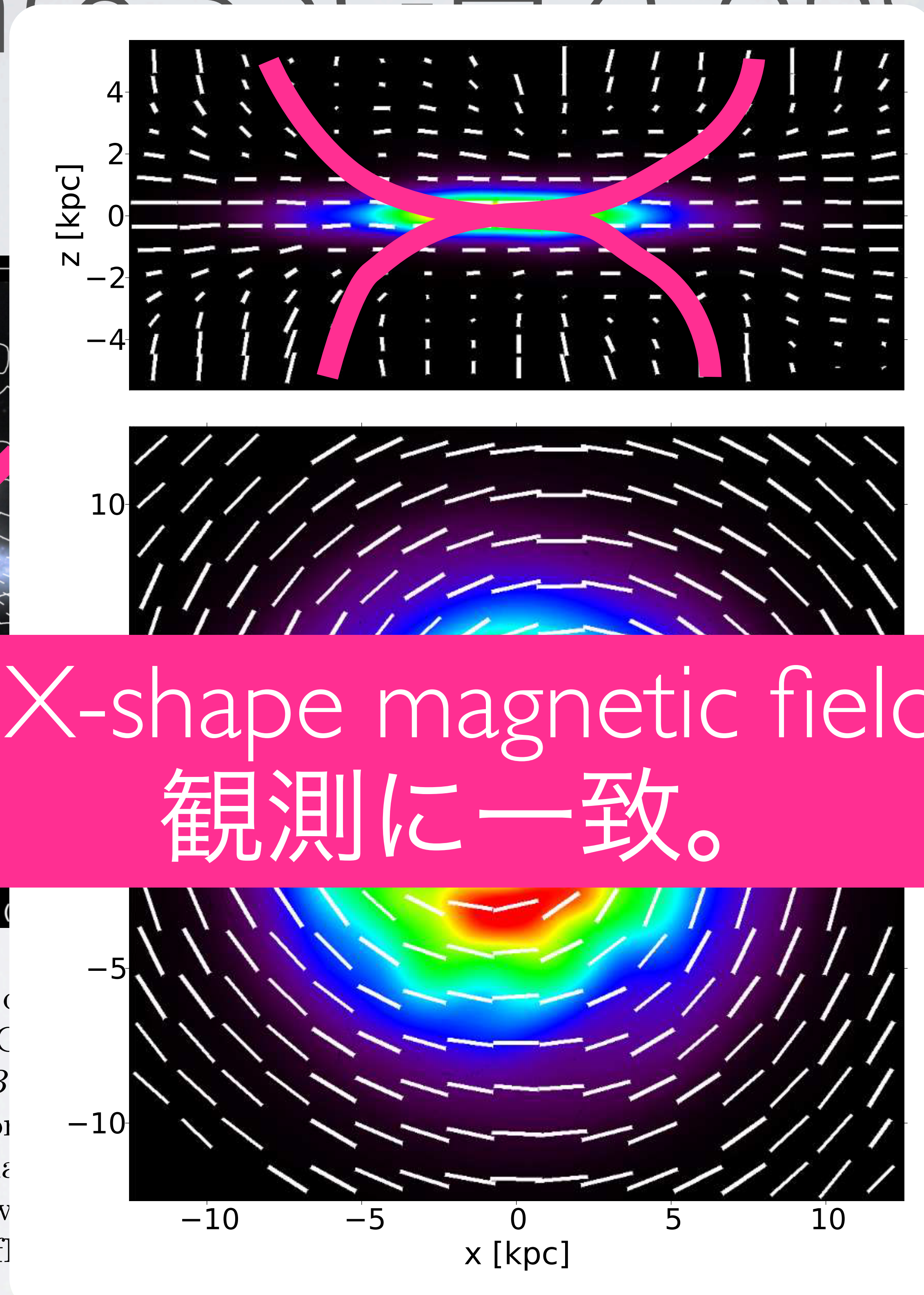
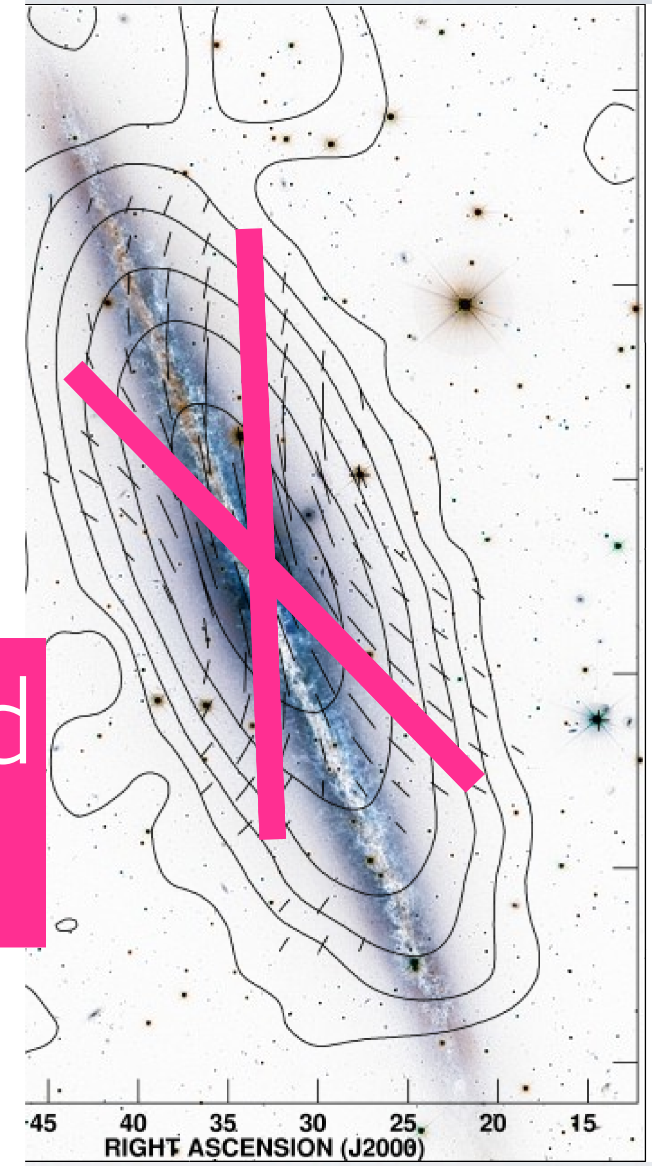


X-shape magnetic field
観測に一致。



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Discussion & Conclusions

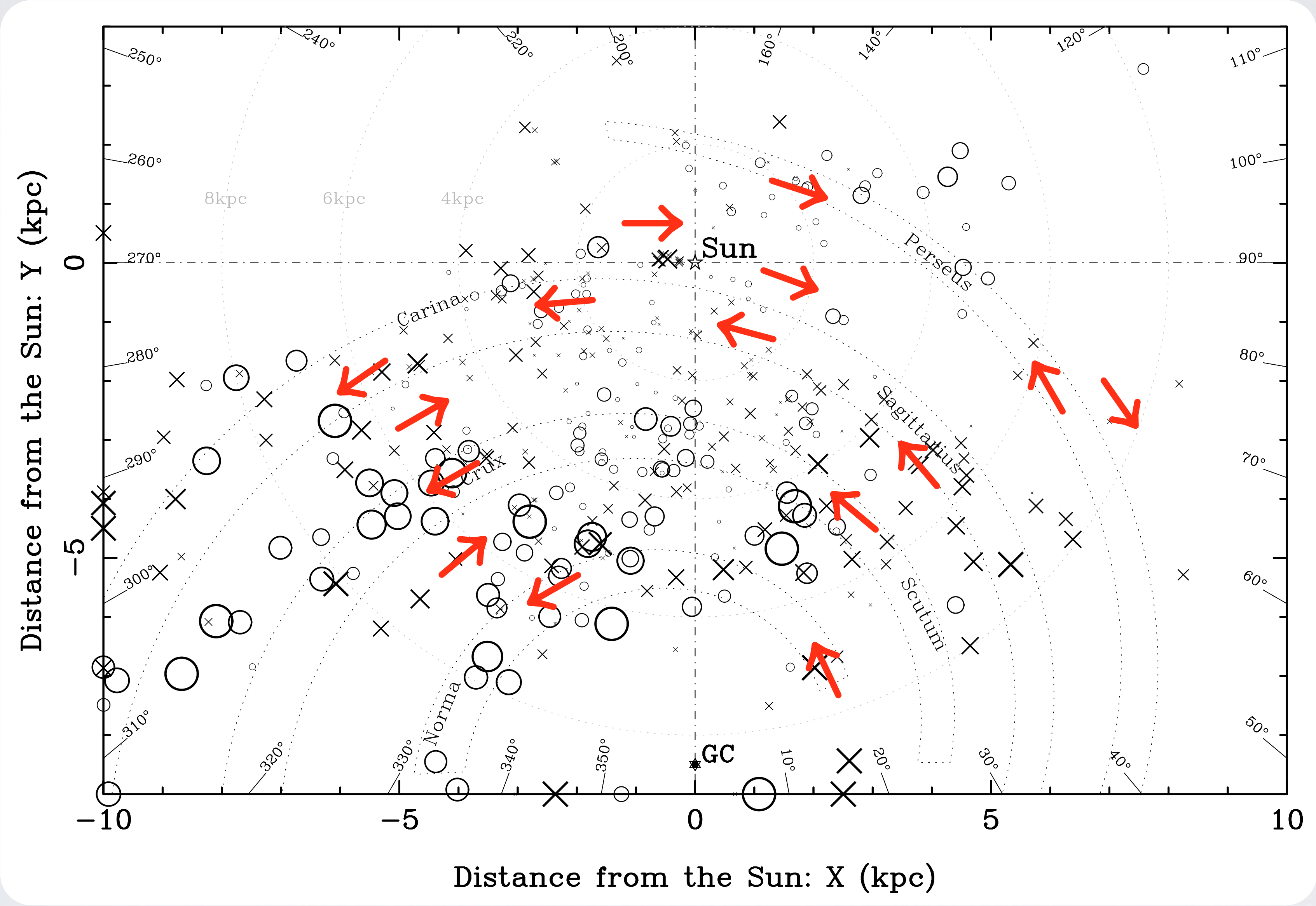
SNRsからmagnetic field & Cosmic Rayを注入するという条件でシミュレーションを行った結果

①初期のrandom, small scale magnetic fieldからlarge scale magnetic fieldが生成

②磁場成長率は270Myr(r=10kpcでのrotation periodと同程度)

Discussion & Conclusions

③方位角方向磁場に(Milky Wayに見られるような)反転が見られない===>spiral armが必要？



Han & Zhang 2007

End.

予備スライド

MHD equations with CR

運動方程式にCosmic Rayの効果を導入。

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}\cdot\nabla)\mathbf{v} = -\frac{1}{\rho}\nabla\left(p + \boxed{p_{\mathrm{cr}}} + \frac{B^2}{8\pi}\right) + \frac{(\mathbf{B}\cdot\nabla)\mathbf{B}}{4\pi\rho} - \nabla\Phi$$

Cosmic Ray pressure

Cosmic Rayのエネルギー方程式は流体の方程式とは別個に解く。

Cosmic Ray diffusion

$$\frac{\partial e_{\mathrm{cr}}}{\partial t} + \nabla(e_{\mathrm{cr}}\mathbf{v}) = \boxed{\nabla(\hat{K}\nabla e_{\mathrm{cr}})} - p_{\mathrm{cr}}(\nabla\cdot\mathbf{v}) + \boxed{Q_{\mathrm{SN}}}$$

Source term

$$p_{\mathrm{cr}} = (\gamma_{\mathrm{cr}} - 1)e_{\mathrm{cr}},\ \gamma_{\mathrm{cr}} = 14/9$$

$$\boxed{K_{ij} = K_{\perp}\delta_{ij} + (K_{\parallel} - K_{\perp})\frac{B_i B_j}{B^2}}$$