Global MHD simulation for asymmetric magnetic reconnection

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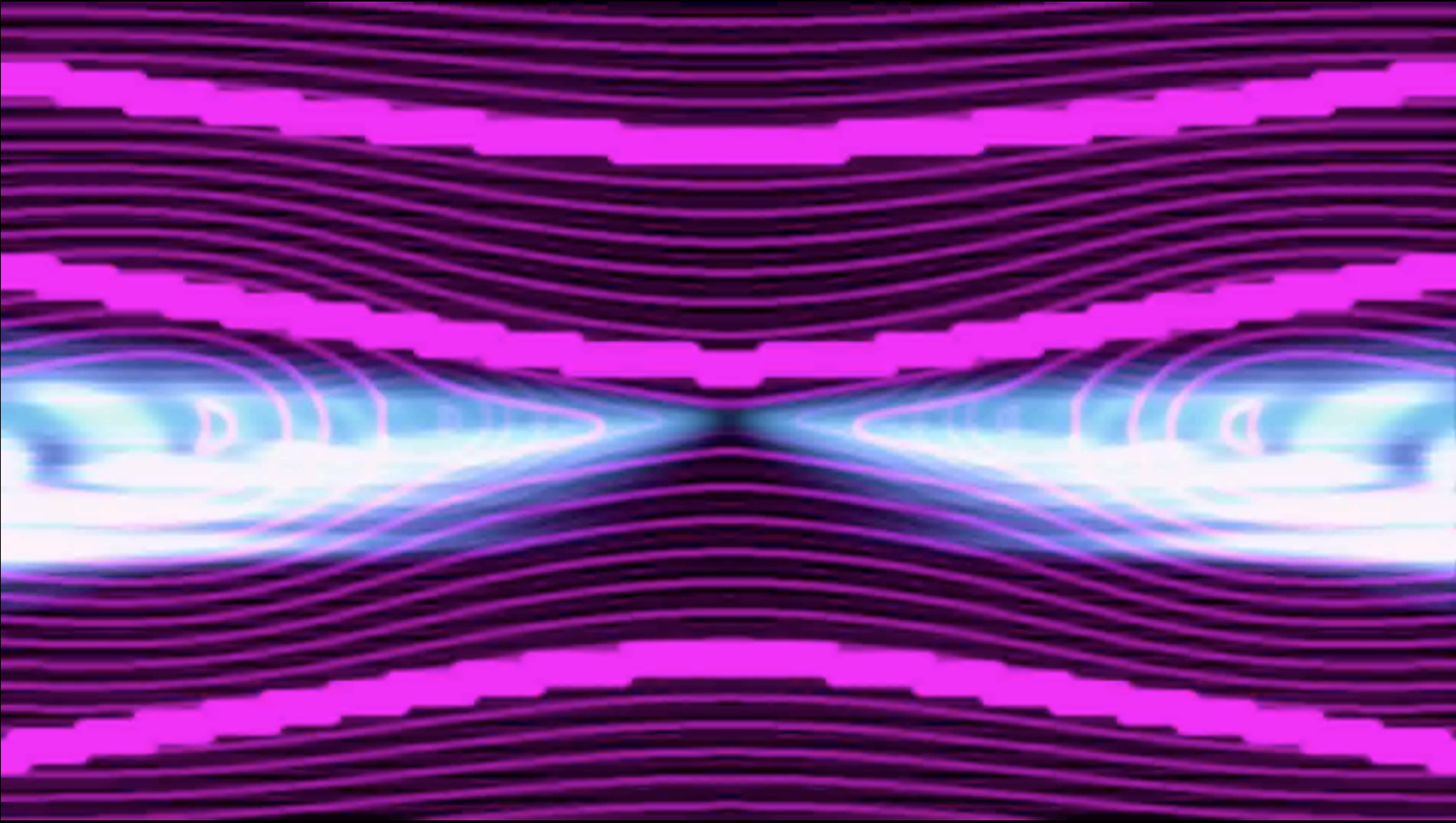
Magnetic reconnection

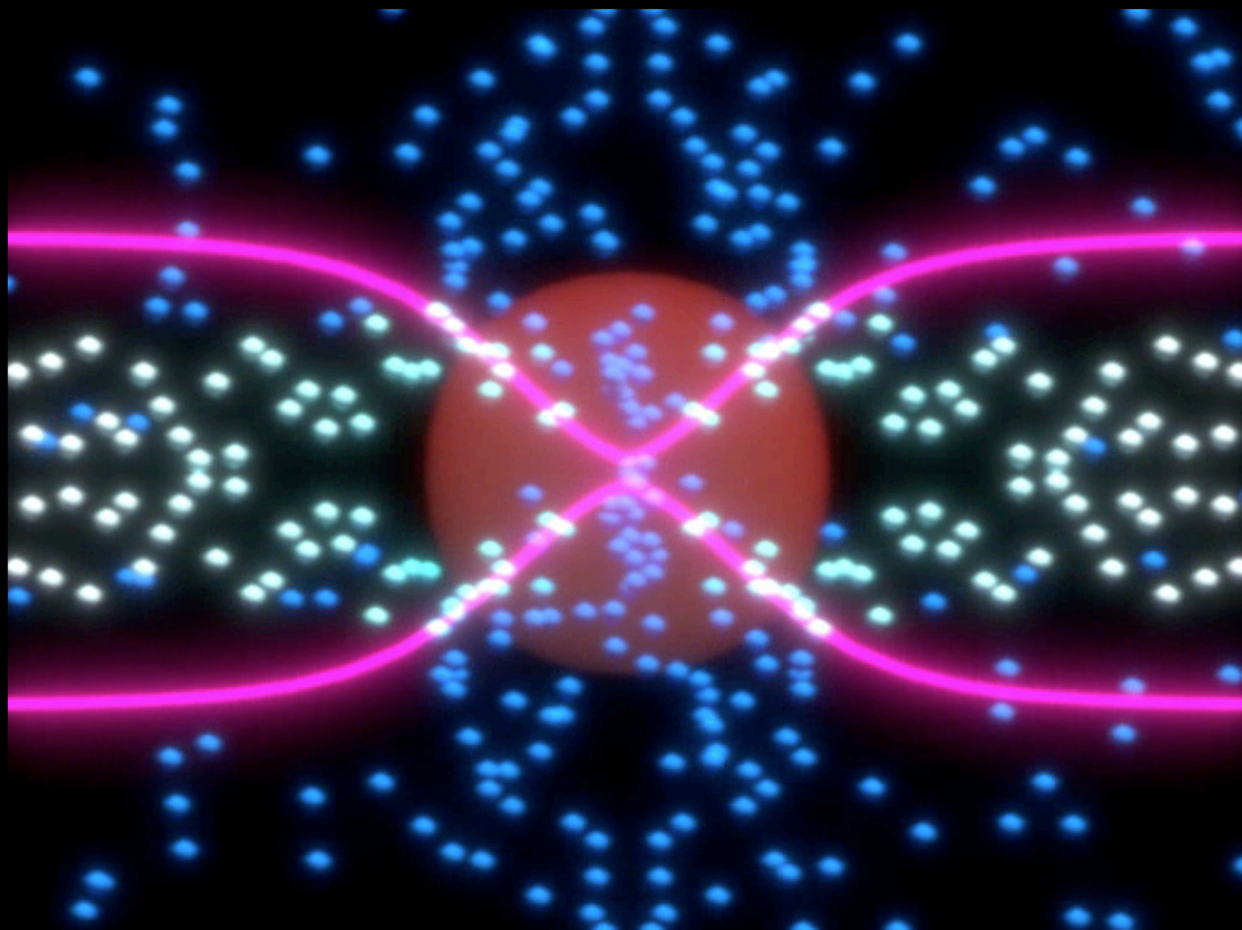
Magnetic reconnection:
The magnetic topology is rearranged and the magnetic energy converts into thermal energy and particle acceleration.
For example,
-Magnetar magnetosphere (flare)
-Solar flare
-Earth magnetosphere
Strongly magnetized compact object has reconnection site.

Example: Asymmetric reconnection



Please give us a data of 3D magnetic field for precise visualization.

Reconnection model



Reconnection rate:
It become an indicator of energy conversion.

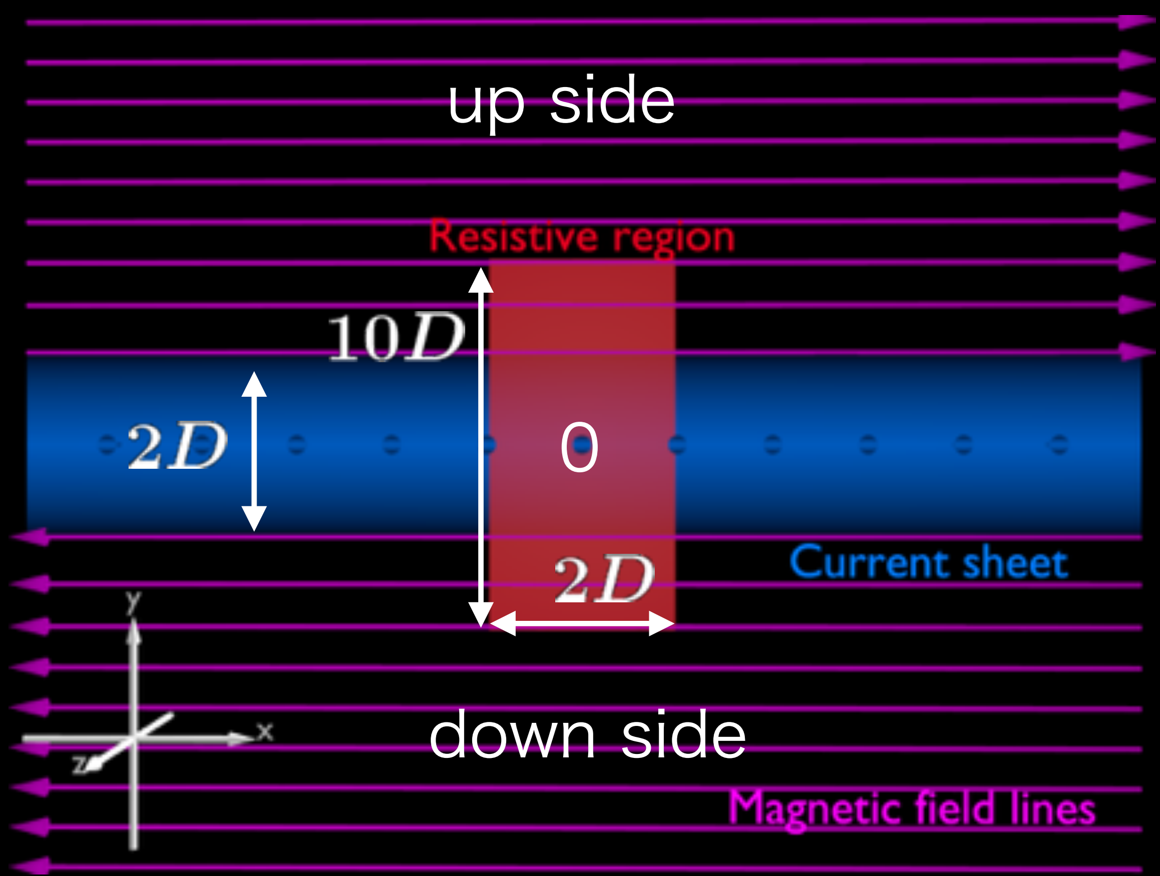
- Sweet Parker model
  $R \propto R_m^{-1/2}$
  Slow energy conversion process
- Petschek model
  $R \propto \log(R_m)^{-1}$
  Fast energy conversion process!

Petschek model is preferable for high energy astrophysical phenomena.

Symmetric case → Many previous works

Asymmetric case → SP -> Cassak and Shay 2007, 2009
Petschek -> Our research

2D Model



Initial assumption:

- Harris equilibrium with constant temperature
- Ideal gas (Specific heat ratio=5/3)
- Introducing asymmetric parameter k

$$B_x = B_{0,\mathrm{side}} \tanh(y/D)$$

$$B_y = 0 \qquad \text{where} \quad B_{0,\mathrm{side}} = B_{0,\mathrm{d}}/k$$

$$\text{side:} \begin{cases} \text{up side: side} = u, y > 0, k = k_0 \\ \text{down side: side} = d, y \leq 0, k = 1 \end{cases}$$

$$\Rightarrow P_{0,\mathrm{side}}, \rho_{0,\mathrm{side}}, P_{\mathrm{m}0,\mathrm{side}}$$

Plasma beta: $\beta_{0,\mathrm{side}} = \dfrac{P_{0,\mathrm{side}}}{B_{0,\mathrm{side}}^2/(8\pi)}$

Sonic speed: $v_{s0} = v_{A0,\mathrm{side}} \sqrt{\dfrac{\gamma \beta_{0,\mathrm{side}}}{2}}$

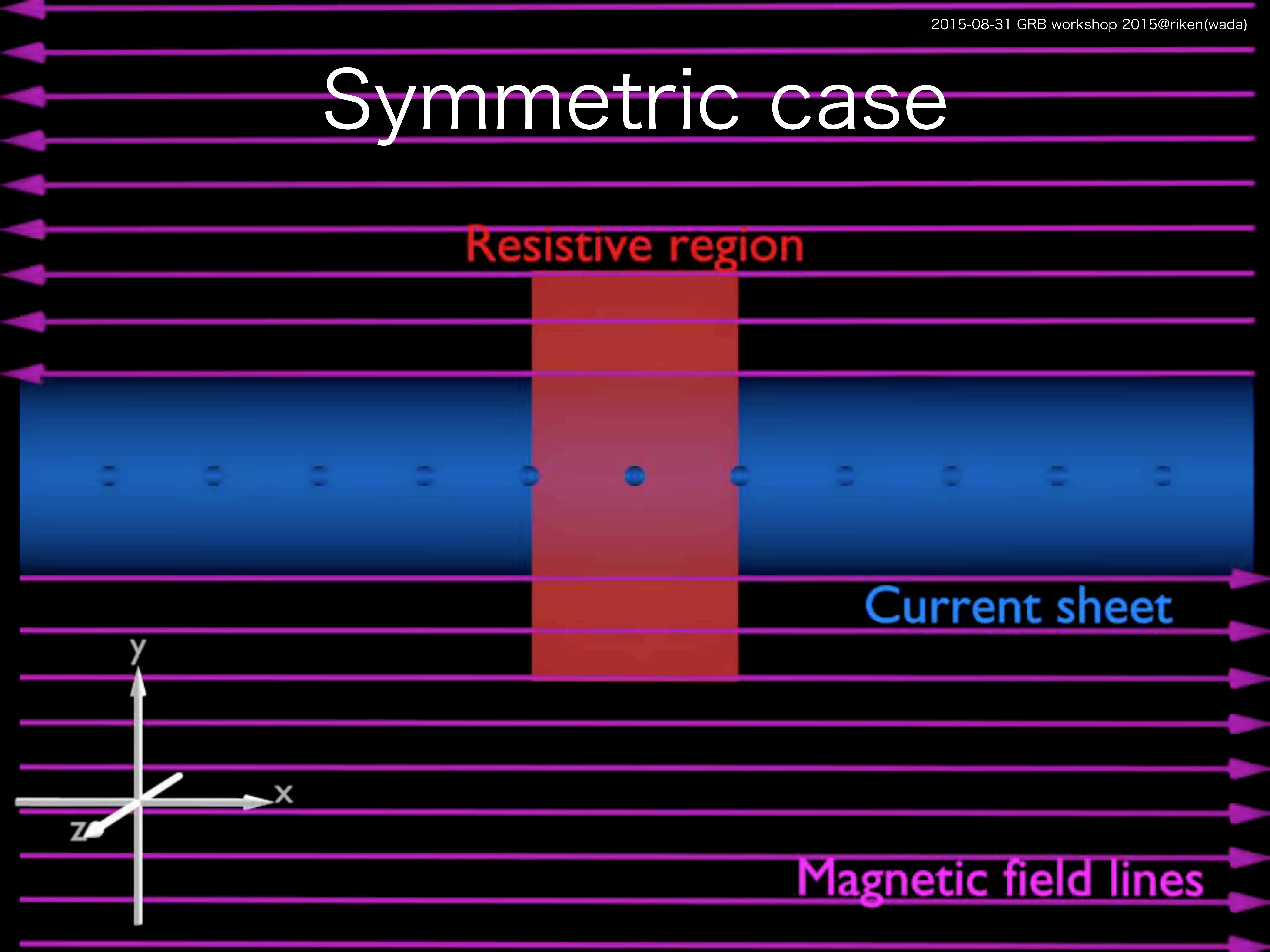
Alfvén speed: $v_{A0,\mathrm{side}} = \dfrac{B_{0,\mathrm{side}}}{\sqrt{4\pi \rho_{0,\mathrm{side}}}}$

$$P_{\mathrm{side,m}} = \frac{B_{0,\mathrm{side}}^2}{8\pi} \tanh^2\left(\frac{y}{D}\right)$$

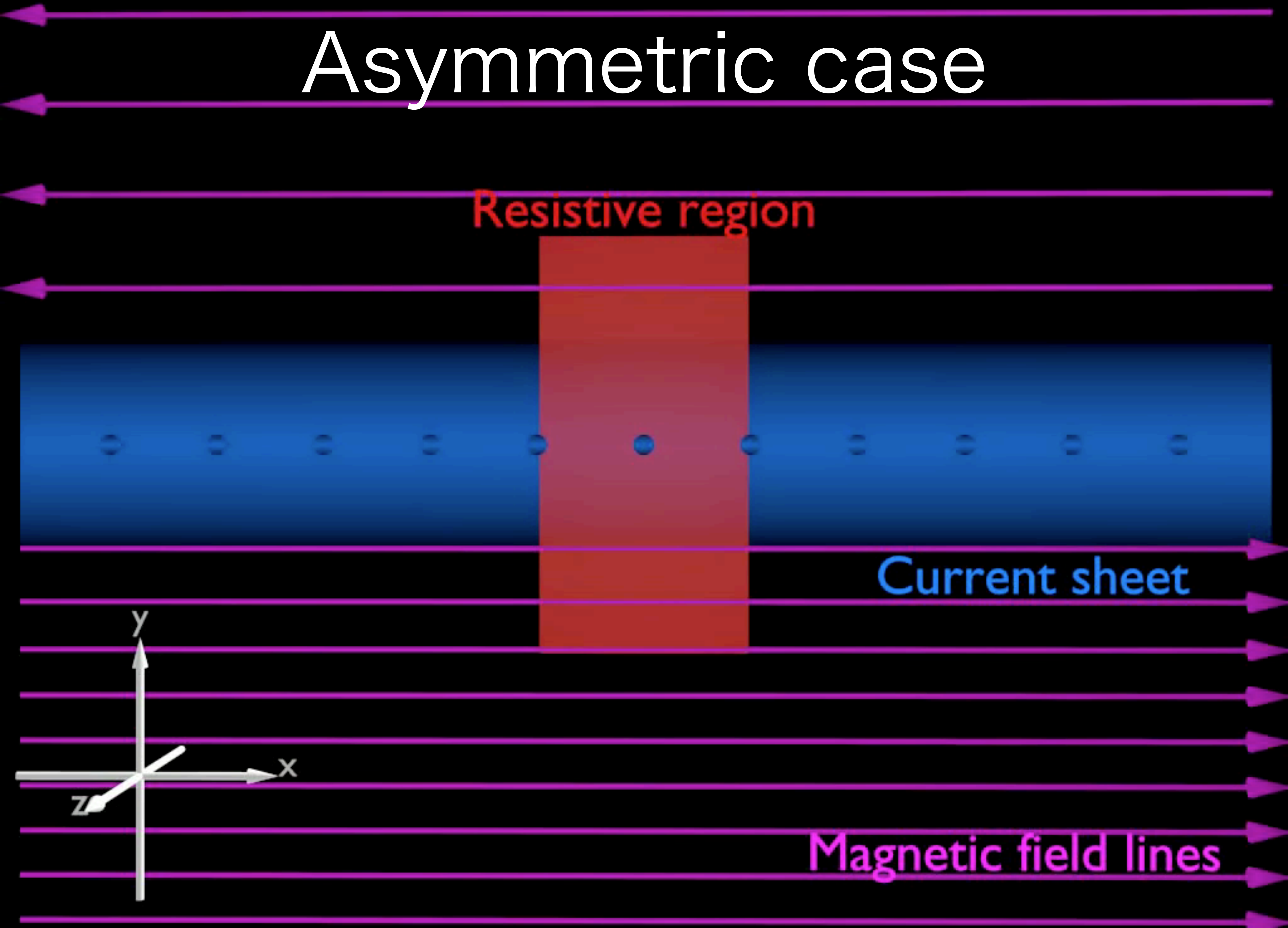
$$P_{\mathrm{side}} = \frac{B_{0,\mathrm{side}}^2}{8\pi} \left[\beta_{0,\mathrm{side}} + \frac{1}{\cosh^2(y/D)}\right]$$

$$\rho_{\mathrm{side}} = \frac{\gamma P_{0,\mathrm{side}}}{v_{s0}^2}$$

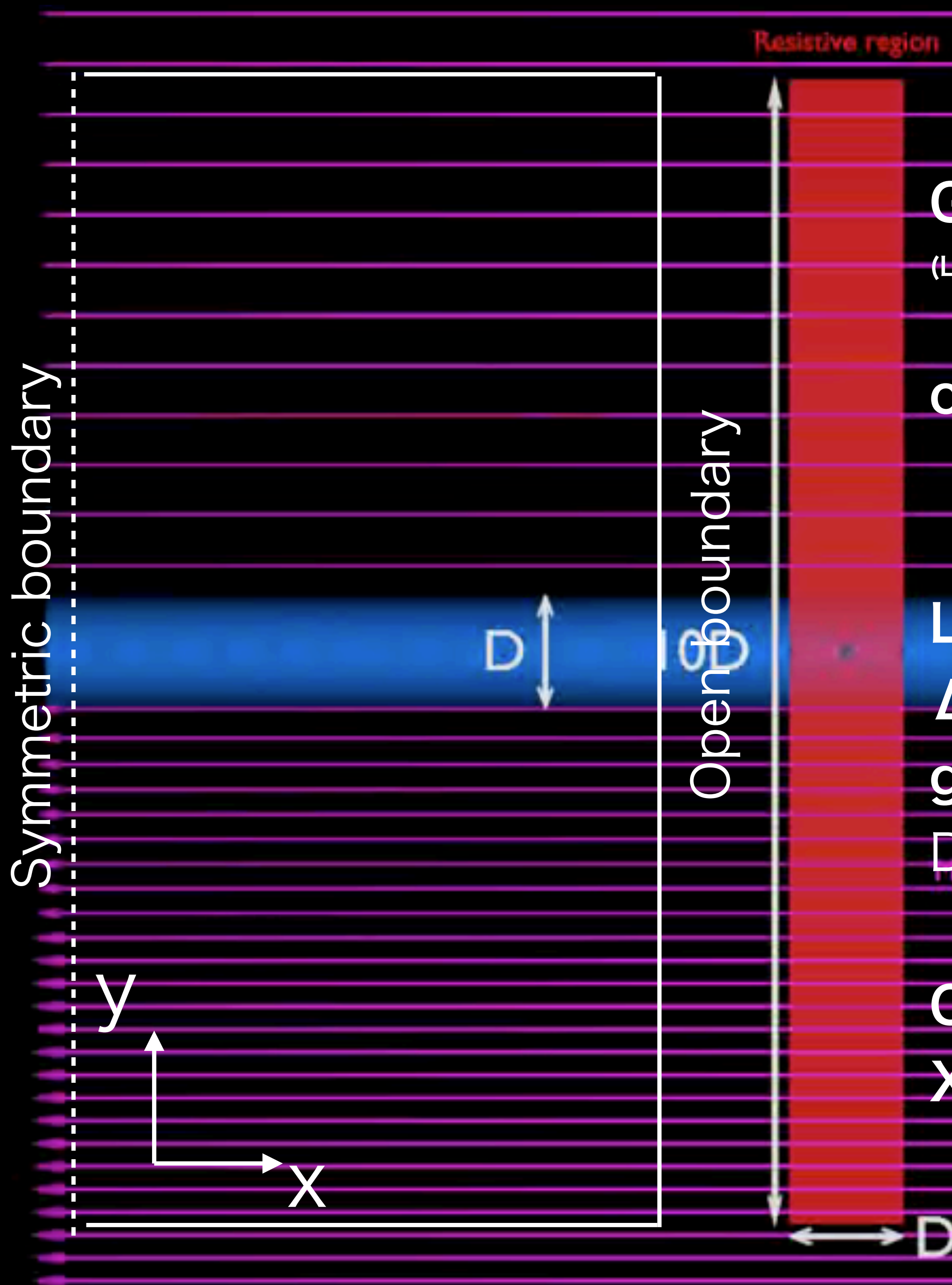
Symmetric case



Asymmetric case



Initial setting of simulation



Global 2D Resistive MHD simulation

(Localized anomalous resistive region: Petschek type reconnection)

code: OpenMHD (Dr. S. Zenitani)
HLLD scheme

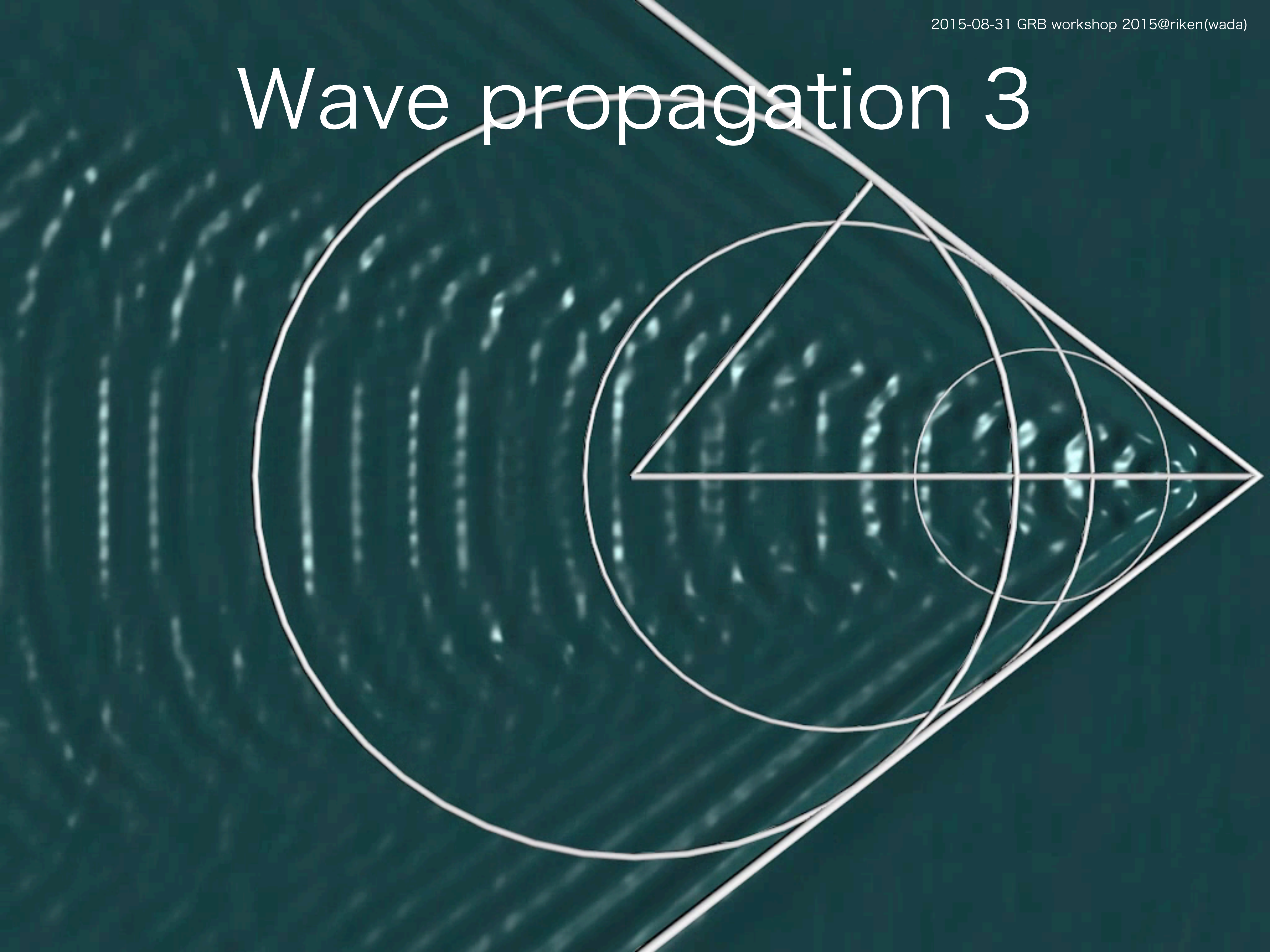
L_x=1280D L_y=2560D
Δ=0.2D CFL=0.3
grid number = 12800x25600
D: initial current sheet thickness

Carried out simulation with Cray XC30, CfCA, NAOJ

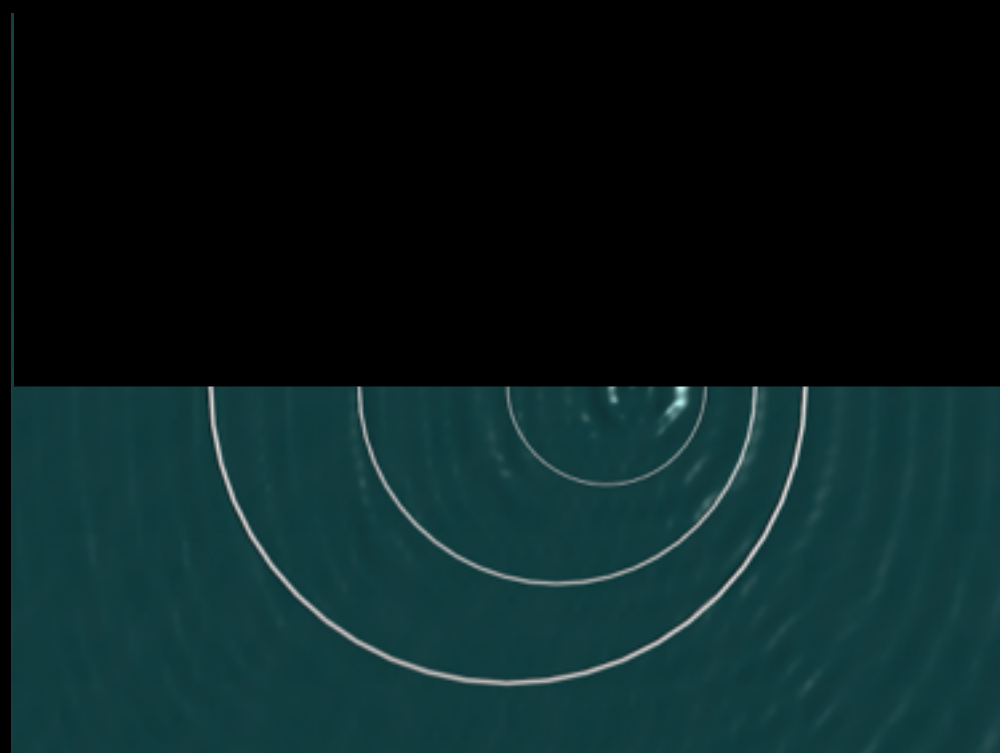
Wave propagation 1

Wave propagation 2

Wave propagation 3



Waves in different matters



+

If different feature (mass density or pressure) materials shares their boundary and wave source moves along the boundary, what's happens?

Waves in different mediums

What's happens in MHD regime?

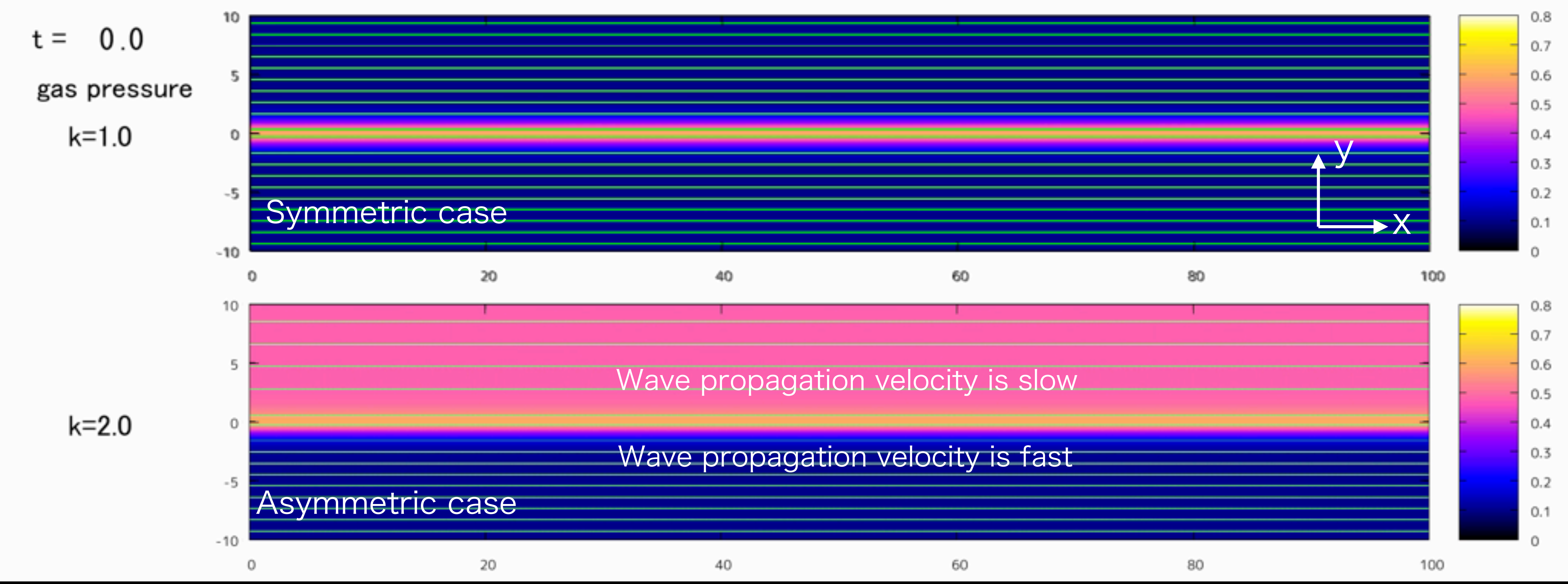
Characteristic phase velocity

-Alfvén mode

-fast mode

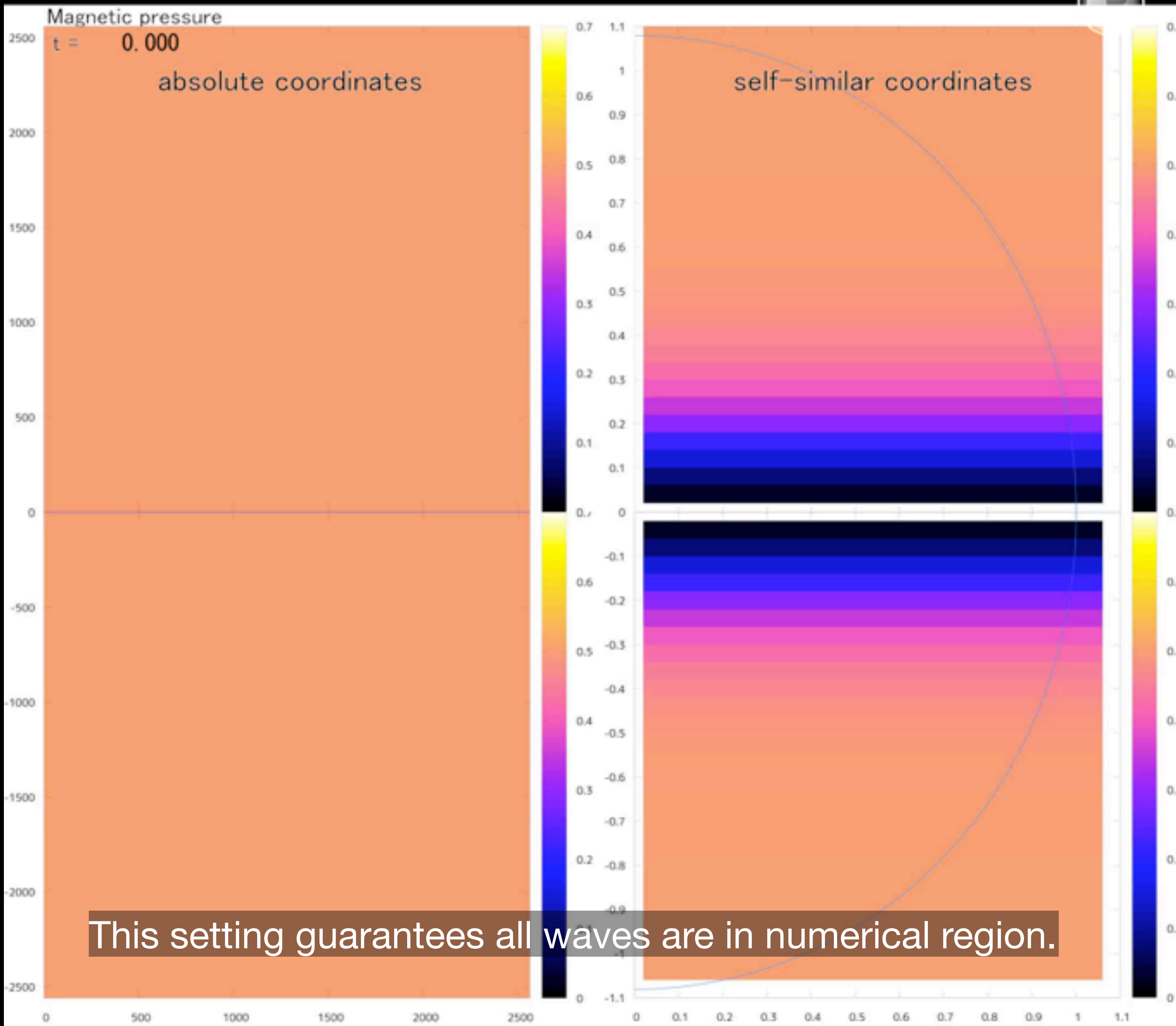
-slow mode

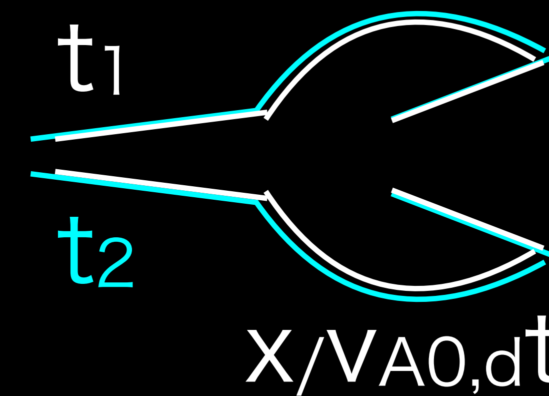
Test run



Inflow (y-direction) to resistive region and plasma become jet (x-direction). Plasmoid forms crab-hand shape.
There is difference of phase velocity of waves (Alfvén, slow, fast) in up or down side. It changes shape of plasmoid.

Self-similar state





To reconstruct self-similar solution of Nitta et al 2001 ApJ with asymmetric case,

- large area
- long time calculation
- enough resolution

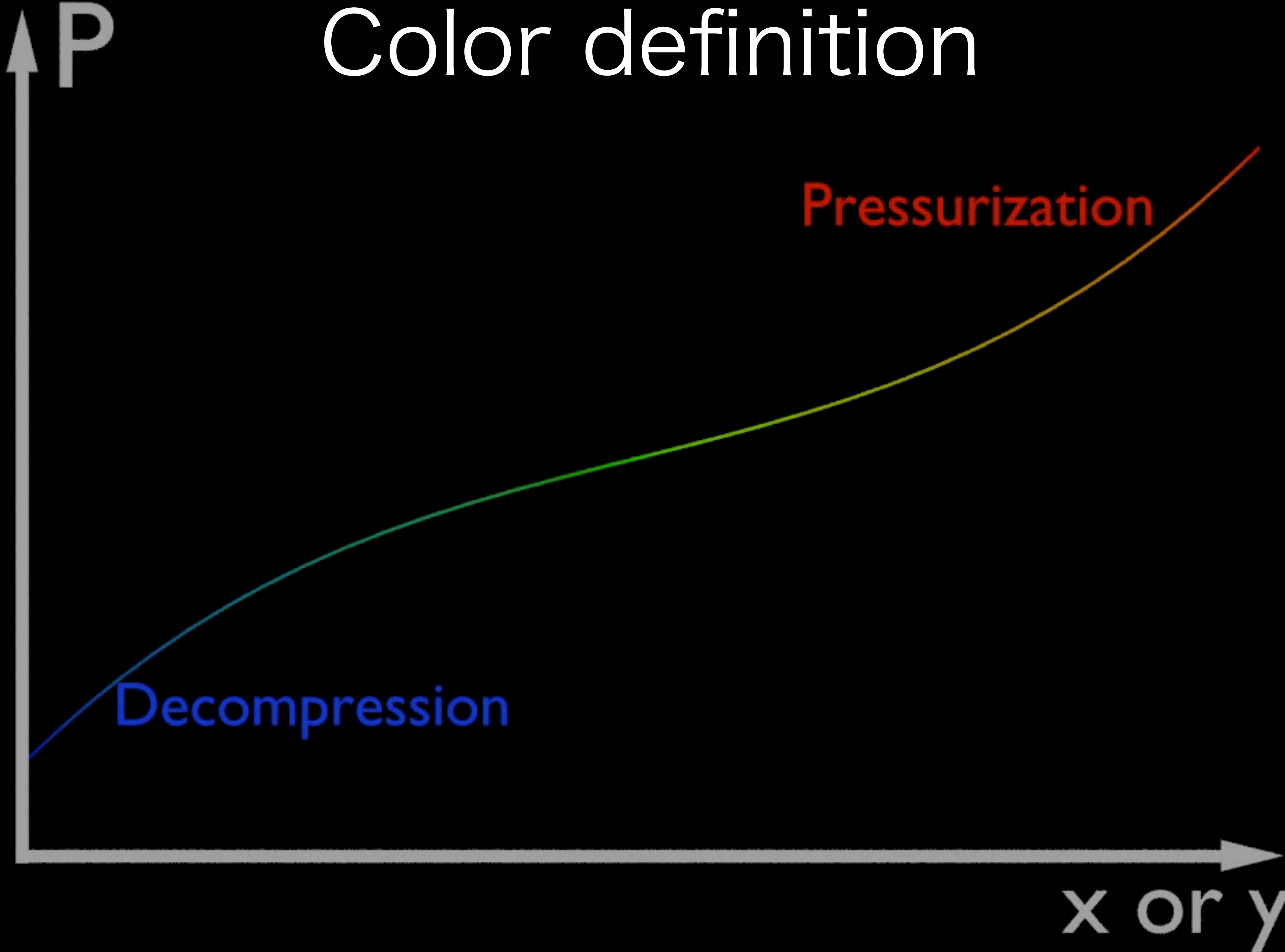
L_x=1280D L_y=2560D

Δ=0.2D

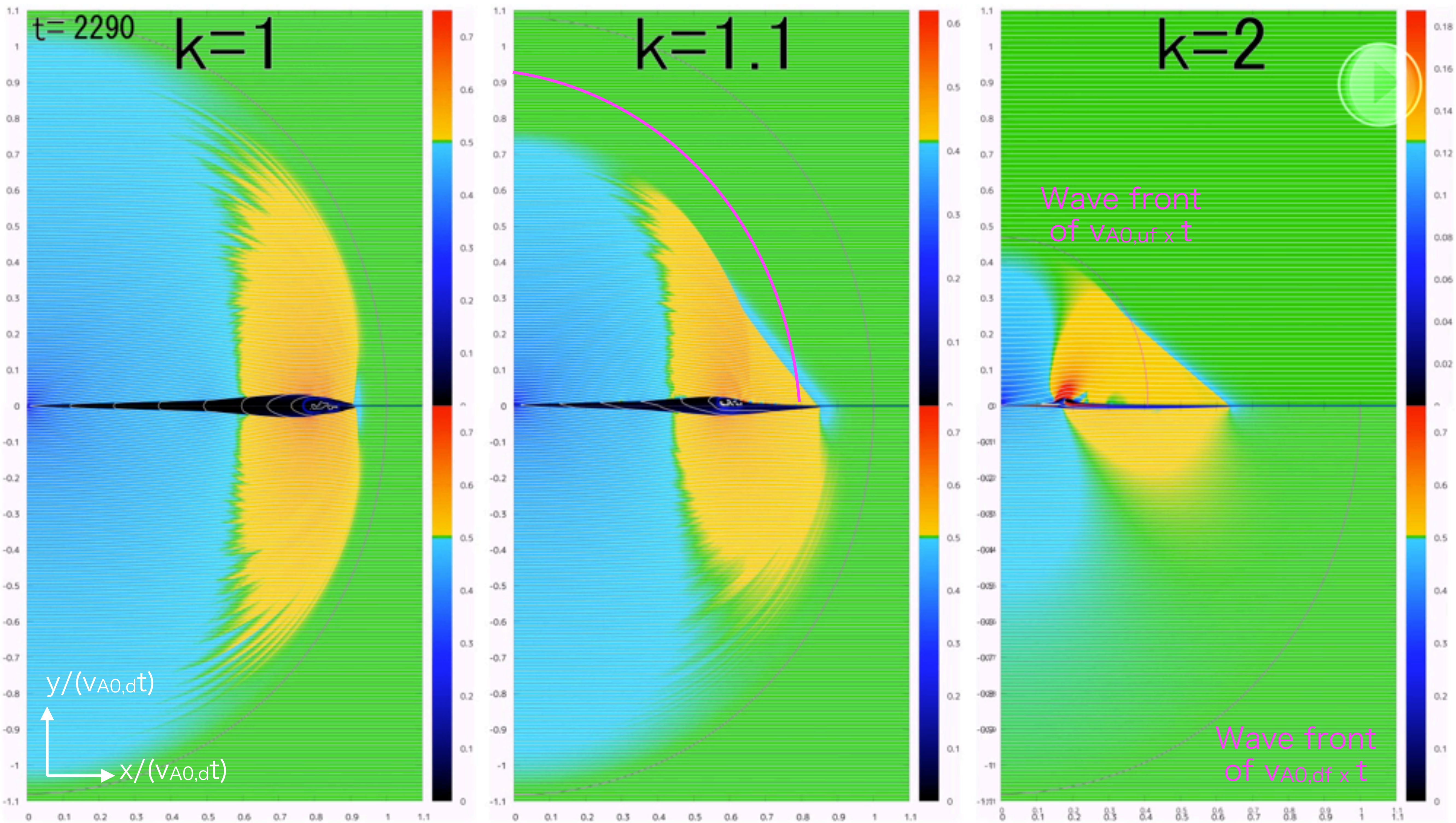
grid=12800x25600

t_{end}=2300D/$v_{A0,d}$

Color definition



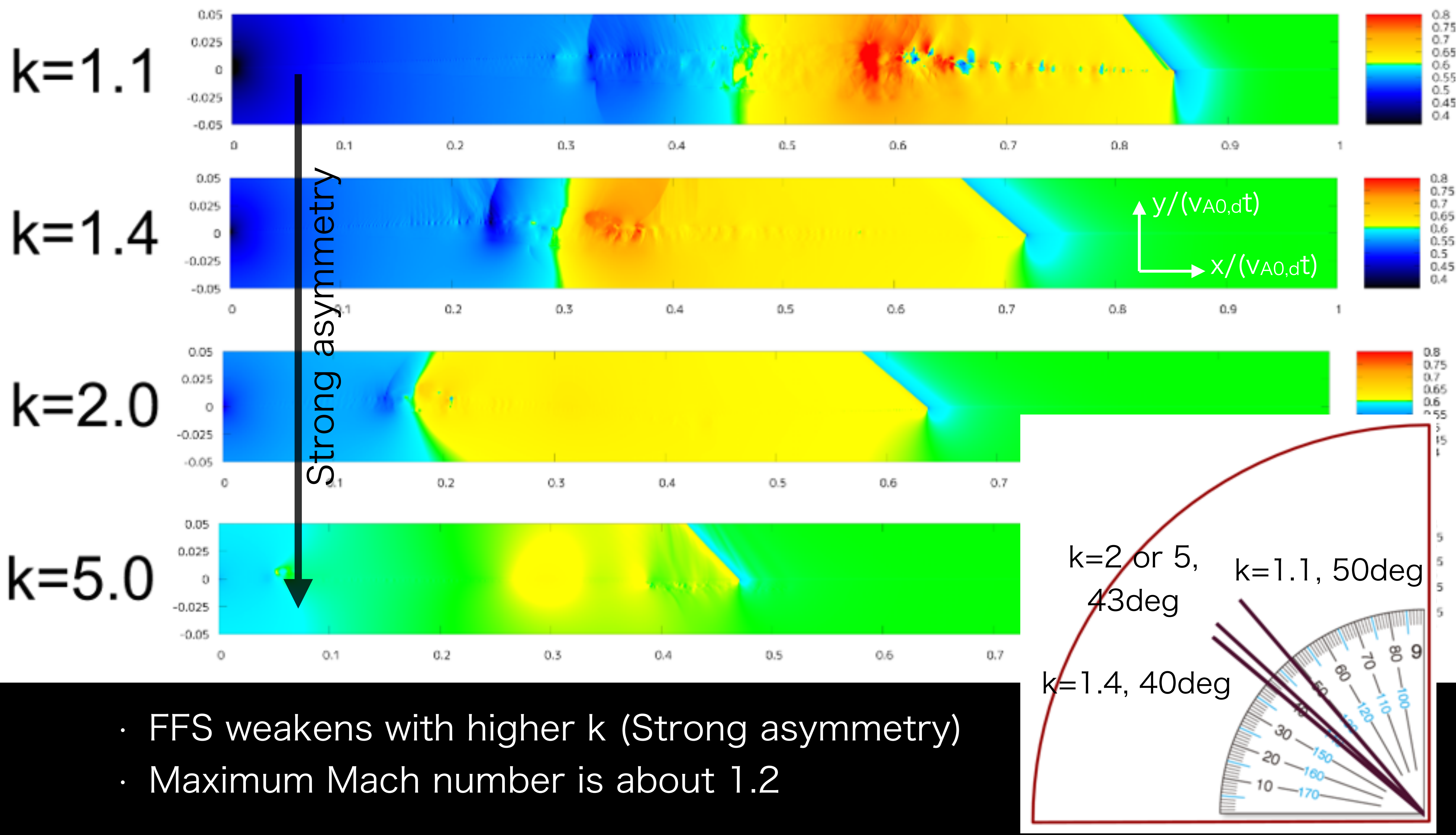
Fast forward shock



Strong asymmetry

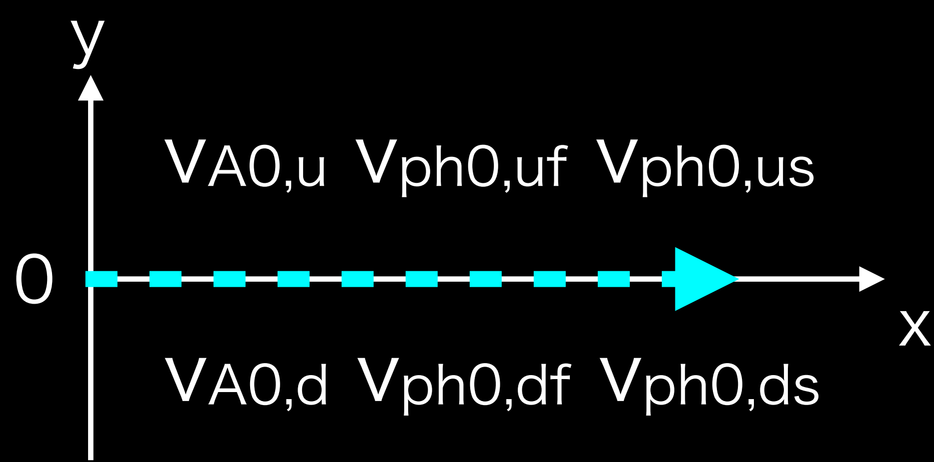
Fast forward shock

Total pressure (pressurized: red dicompressed: blue)

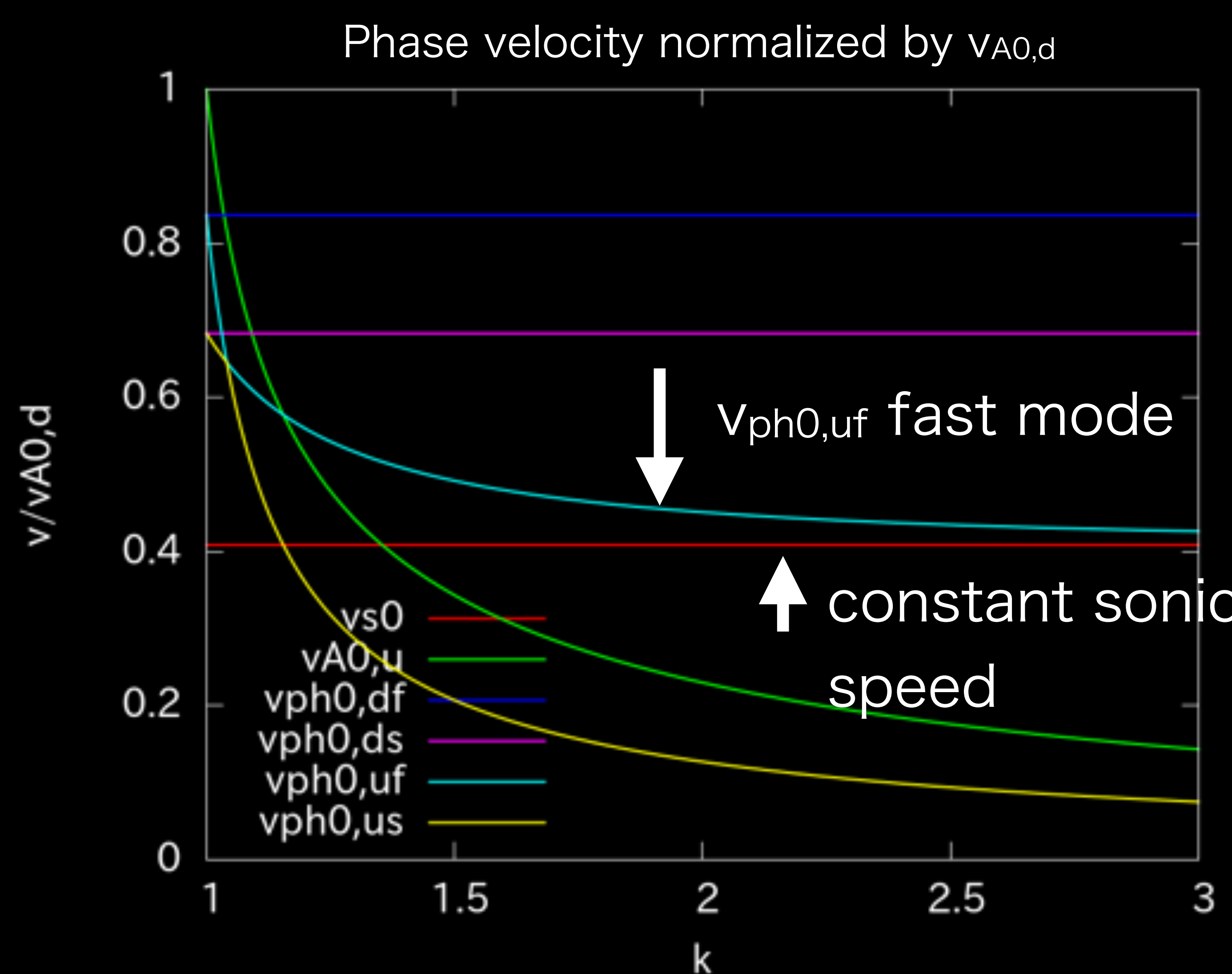


- FFS weakens with higher k (Strong asymmetry)
- Maximum Mach number is about 1.2

Phase velocity with k



We can solve phase velocity (fast, slow, Alfven) with linear perturbation method of MHD equations on x-axis.



$$v_{\mathrm{s0,u}} = v_{\mathrm{s0,d}}$$

$$v_{\mathrm{A0,u}} = v_{\mathrm{A0,d}} \sqrt{\frac{\beta_{0,\mathrm{d}}}{k^2 + k^2\beta_{0,\mathrm{d}} - 1}}$$

$$\sigma_{0,\mathrm{u}} = \frac{8\gamma(k^2 + k^2\beta_{0,\mathrm{d}} - 1)}{1 + 2\gamma(k^2 + k^2\beta_{0,\mathrm{d}} - 1)}$$

$$v_{\mathrm{ph0,side}} = \frac{v_{\mathrm{A0,d}}}{2} \sqrt{\frac{\beta_{0,\mathrm{d}}[2 + \gamma(k^2 + k^2\beta_{0,\mathrm{d}} - 1)]}{k^2 + k^2\beta_{0,\mathrm{d}} - 1}} \sqrt{1 \pm \sqrt{1 - \sigma_{0,\mathrm{u}} \cos^2\theta}}$$

+: fast mode

-: slow mode

FFS in asymmetric reconnection

FFS:
We expect new site of
particle acceleration

Highlighted in red-pink: The region where pressure difference from initial equilibrium is large

Summary

We performed global high resolution 2D resistive MHD simulation.

- Our previous solution (Nitta et al) is reconstruct with asymmetric case
- Forward fast shock(FSS) is formed from the edge of crab hand.
- FFS is formed in k>1 〜 k< 10

We often consider reconnection as a energy converter from magnetic energy to particle kinetic energy.

But there is another possibility of particle acceleration by asymmetric reconnection. We will be looking for application of our model in future work.

- ⋆ Magnetic reconnection in striped pular wind -> higher mach number shock with multiple asymmetric reconnection

Acknowledgments

Thanks to all member of plasma seminar in NAOJ. We also thanks to Dr. S. Zenitani for developing numerical code and data analysis. The movie is rendered by analytical server in CfCA (NAOJ). Special thanks to SCIGRA for scientific 3DCG models and figures.

Center for Computational Astrophysics

title