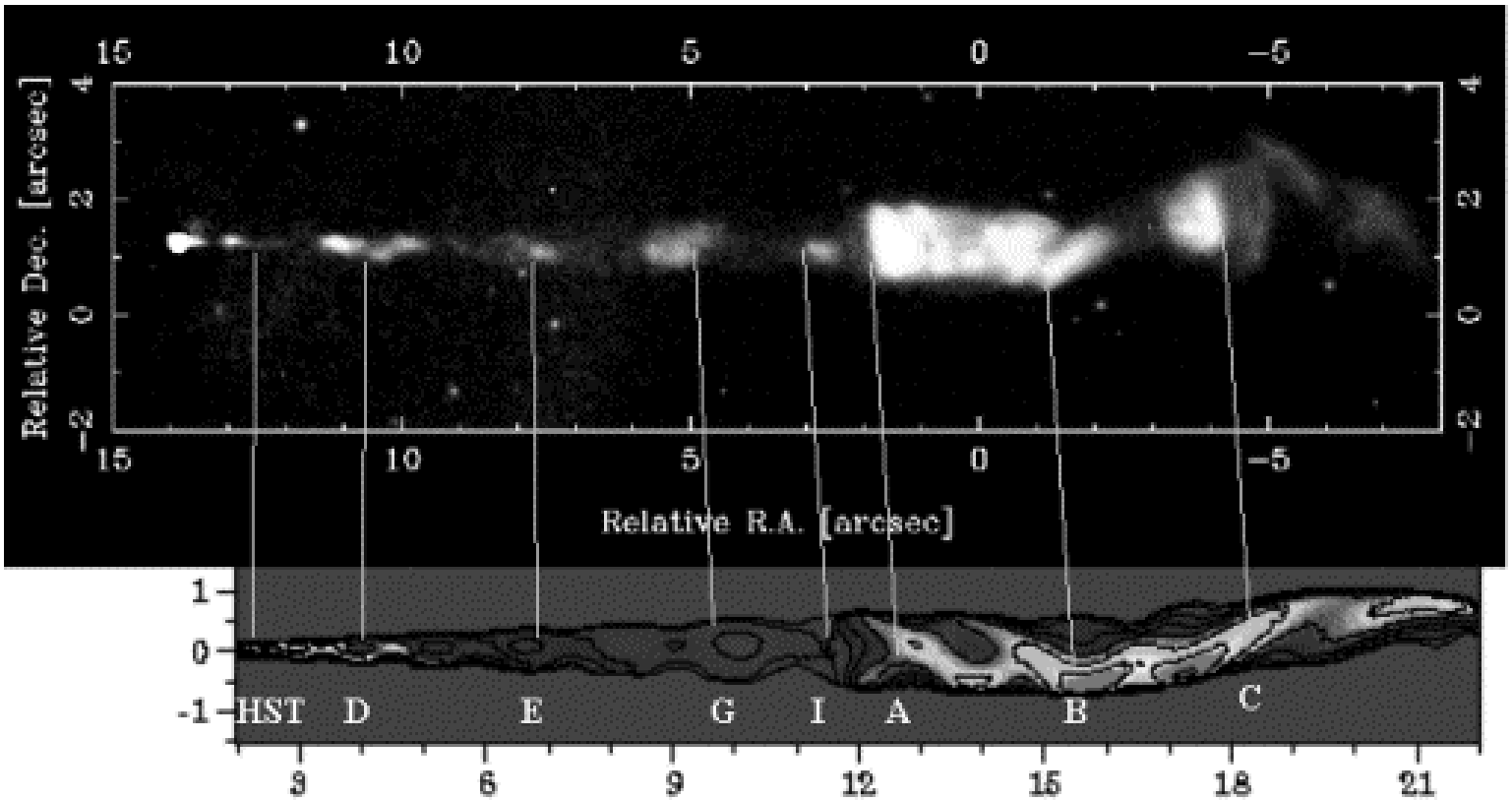
Project 6

Relativistic MHD simulations using CANS

Tao Cai (Purple Mountain Observatory, China)
Nicolas Vasquez (TiTech, Japan)
Ryuho Kataoka (NICT, Japan)

Supervised by Asano san (Chiba University)

Introduction: Jet and K-H instability



(Lobanov et al., 2003)

Internal structure of the kiloparsec-scale jet in M87, possibly related with Kelvin-Helmholtz instability

Special Relativistic Ideal MHD

$$
\begin{cases}
\dfrac{\partial D}{\partial t} + \nabla \cdot \left(D\mathbf{v} \right) = 0 \\
\dfrac{\partial \mathbf{P}}{\partial t} + \nabla \cdot \left[p\mathbf{I} + \left(e + p \right) \dfrac{\gamma^2}{c^2} \mathbf{vv} - \dfrac{1}{4\pi} \left\{ \mathbf{EE} + \mathbf{BB} - \dfrac{1}{2} \left(E^2 + B^2 \right) \right\} \right] = 0 \\
\dfrac{\partial \varepsilon}{\partial t} + \nabla \cdot \left[\left\{ \left(e + p \right) \gamma^2 - Dc^2 \right\} \mathbf{v} + \dfrac{c}{4\pi} \left(\mathbf{E} \times \mathbf{B} \right) \right] = 0 \\
\dfrac{\partial \mathbf{B}}{\partial t} + \nabla \times \left(c\mathbf{E} \right) = 0
\end{cases}
$$

$$D = \rho\gamma$$

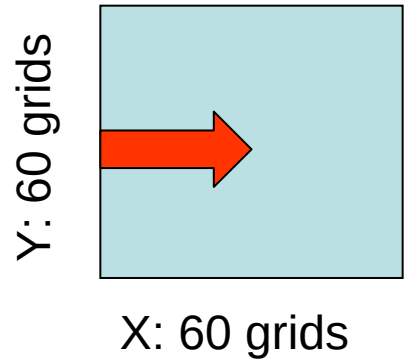
$$\mathbf{P} = \left(e + p \right) \frac{\gamma^2}{c^2} \mathbf{v} + \frac{1}{4\pi c} \left(\mathbf{E} \times \mathbf{B} \right)$$

$$\varepsilon = \left(e + p \right) \gamma^2 - Dc^2 - p + \frac{1}{8\pi} \left(E^2 + B^2 \right)$$

$$\mathbf{E} = -\frac{1}{c} \mathbf{v} \times \mathbf{B}$$

(γ : Lorentz factor, e : thermal enegy density)

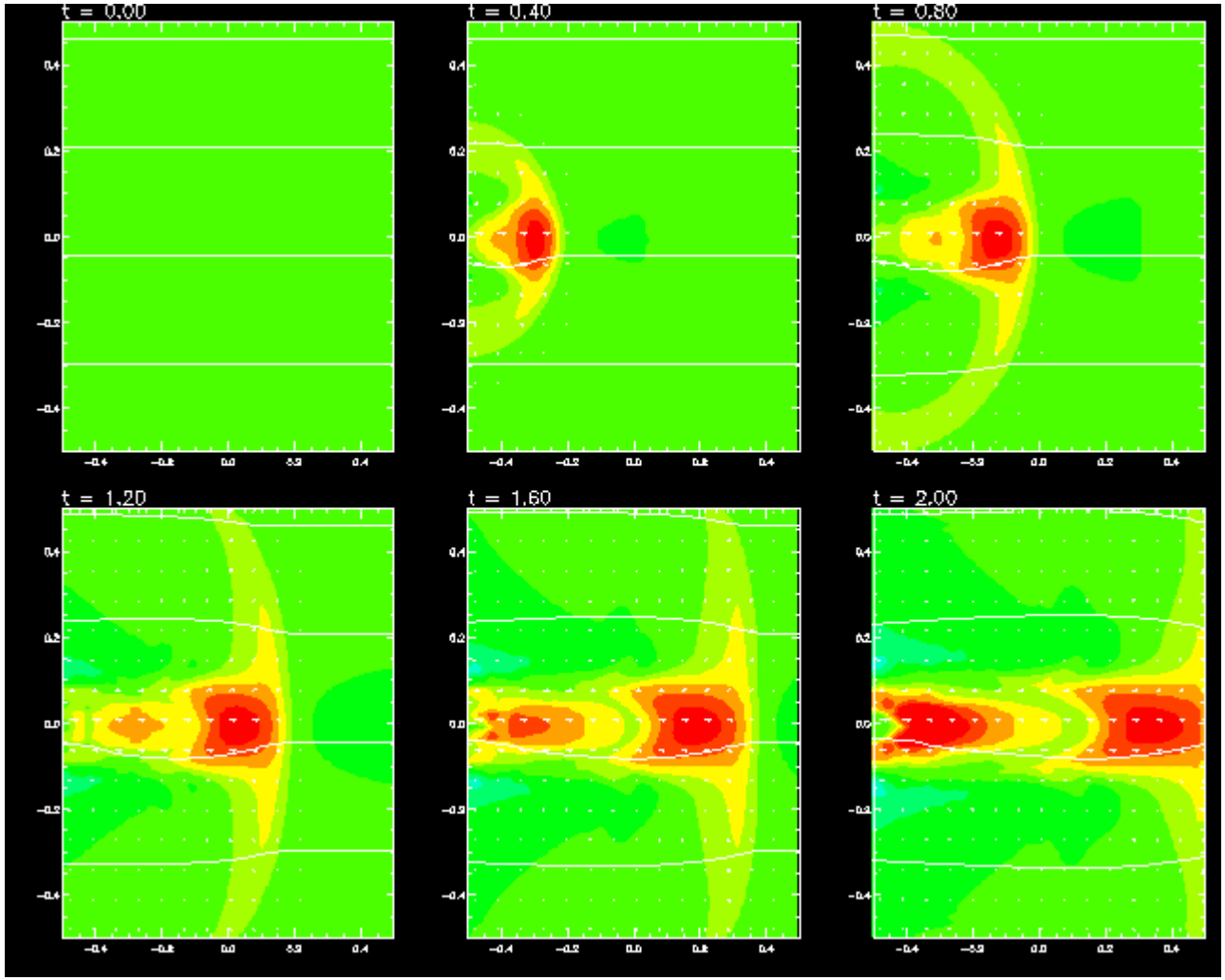
1. Jet



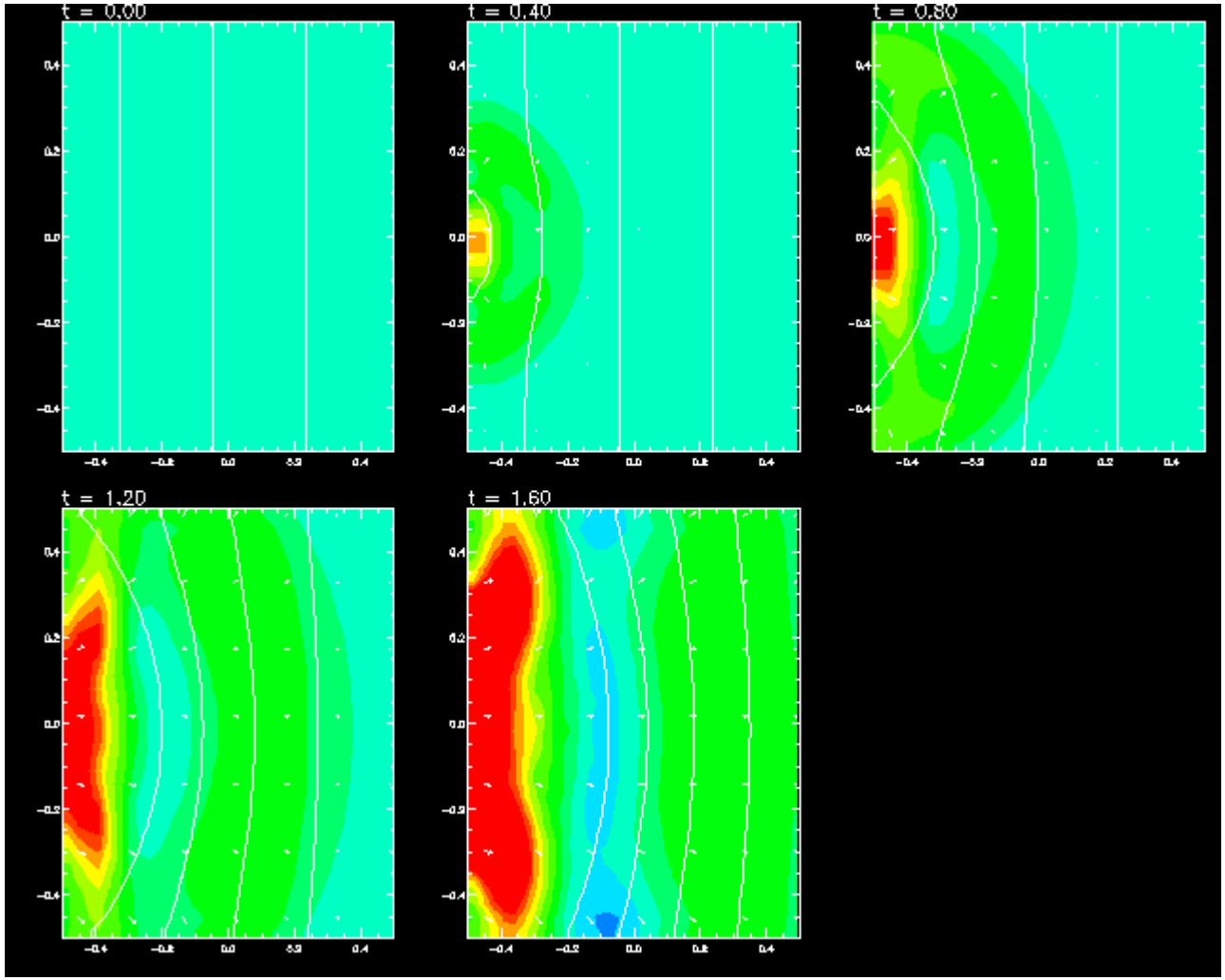
- X: Free, Y: Free
- Continuous plasma Injection of vx=0.5 at x=0

- Magnetic field dependence
  - Strong B field
  - Parallel, perpendicular, and oblique B

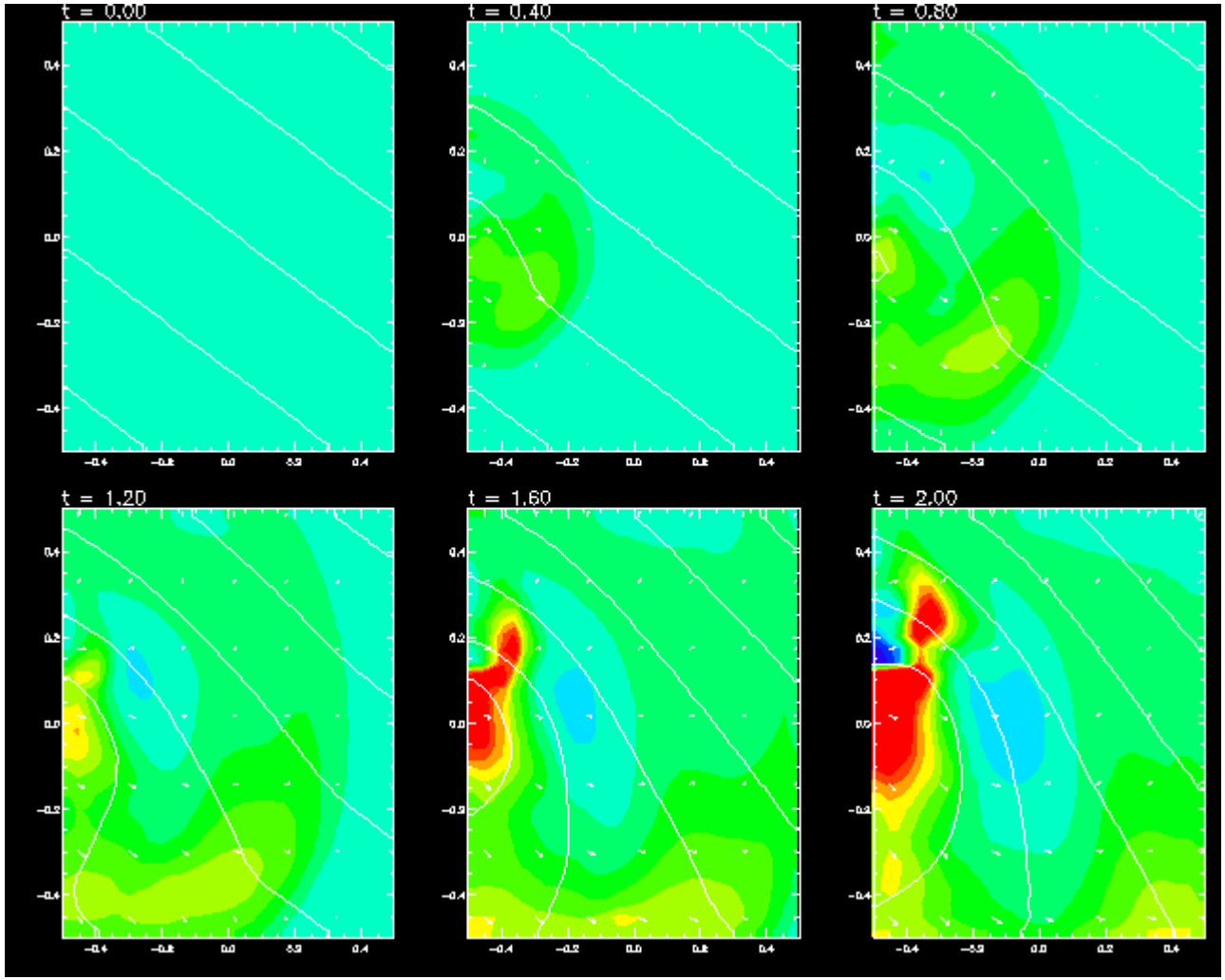
a. Parallel magnetic field



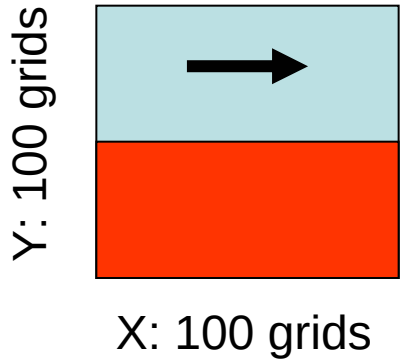
b. Perpendicular magnetic field



c. Oblique magnetic field



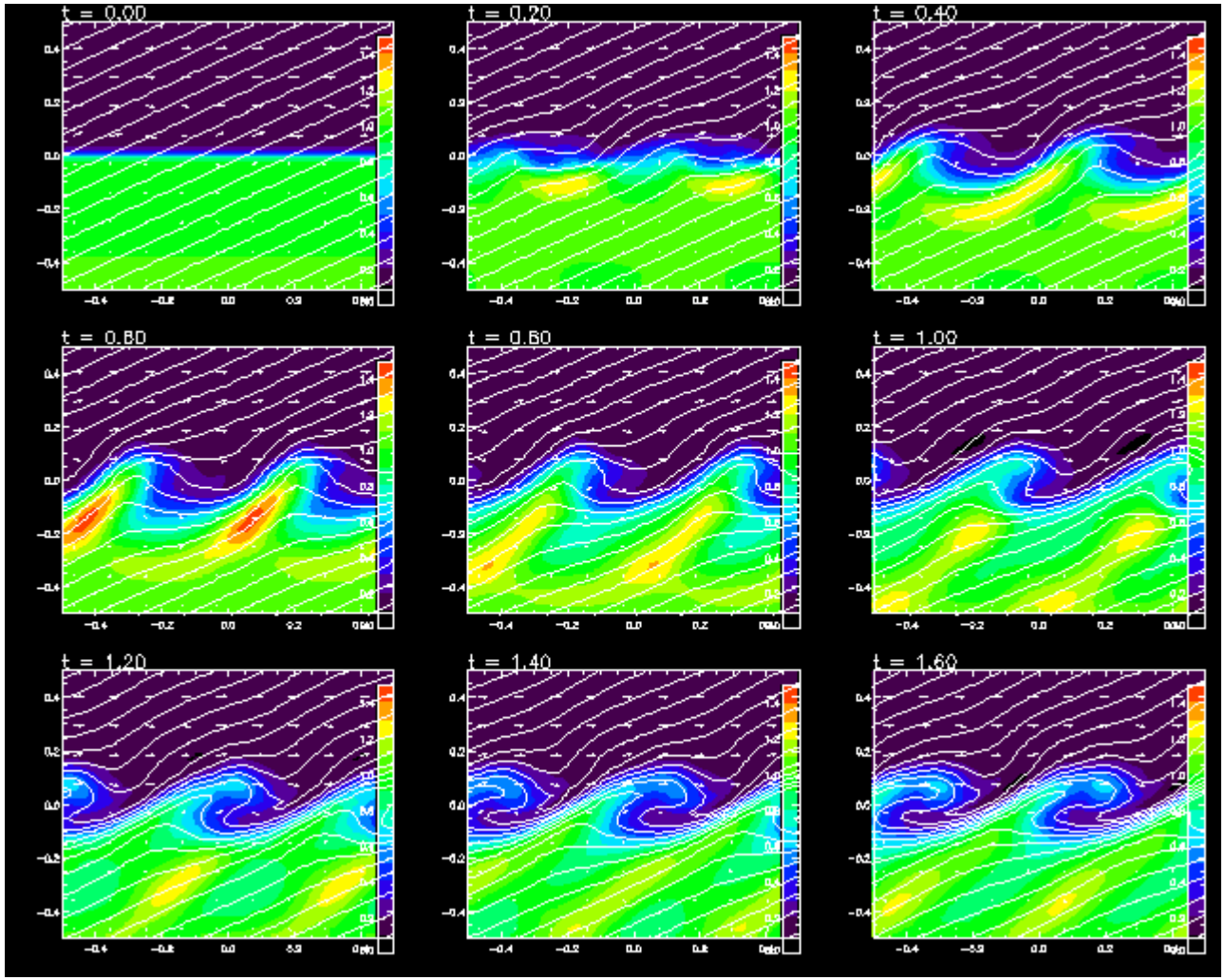
2. K-H Instability



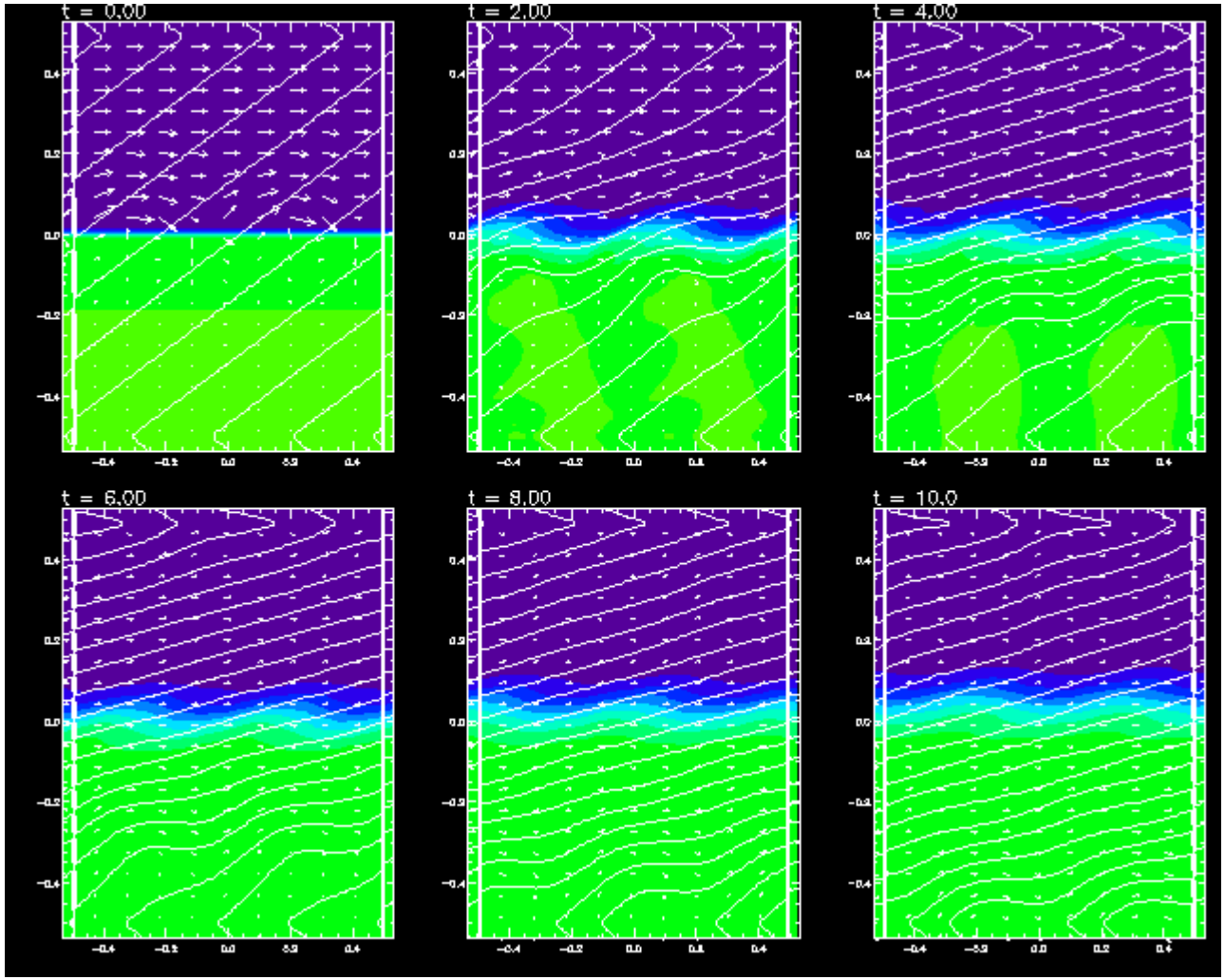
- X: Periodic, Y: Symmetric
- Pressure-balanced layers with velocity shear: perturbation applied

- MHD and relativistic MHD
  - Parallel, perpendicular, and oblique B
- Parametric survey
  - Velocity shear dependence of growth rate

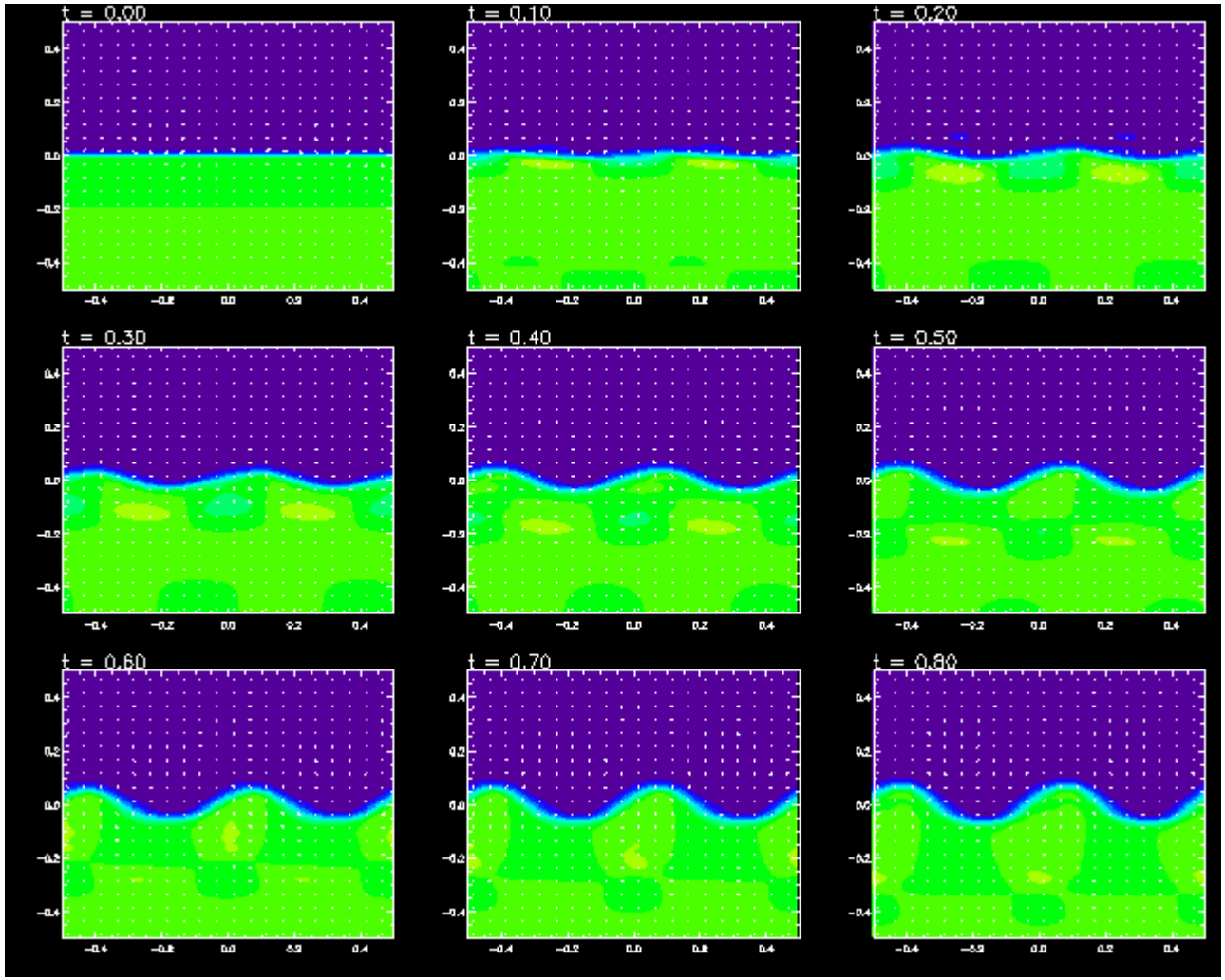
Relativistic MHD



MHD

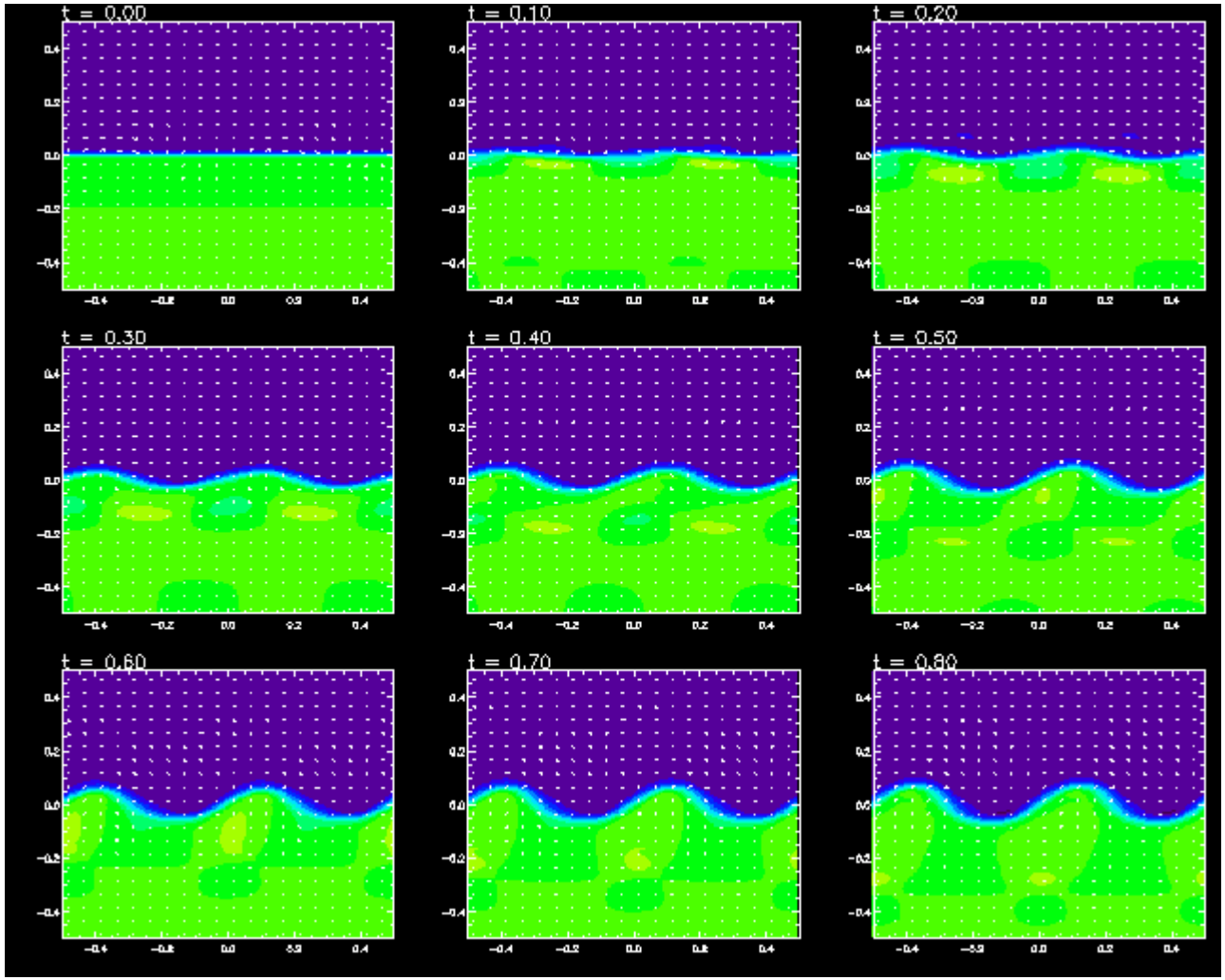


Vx=0.0



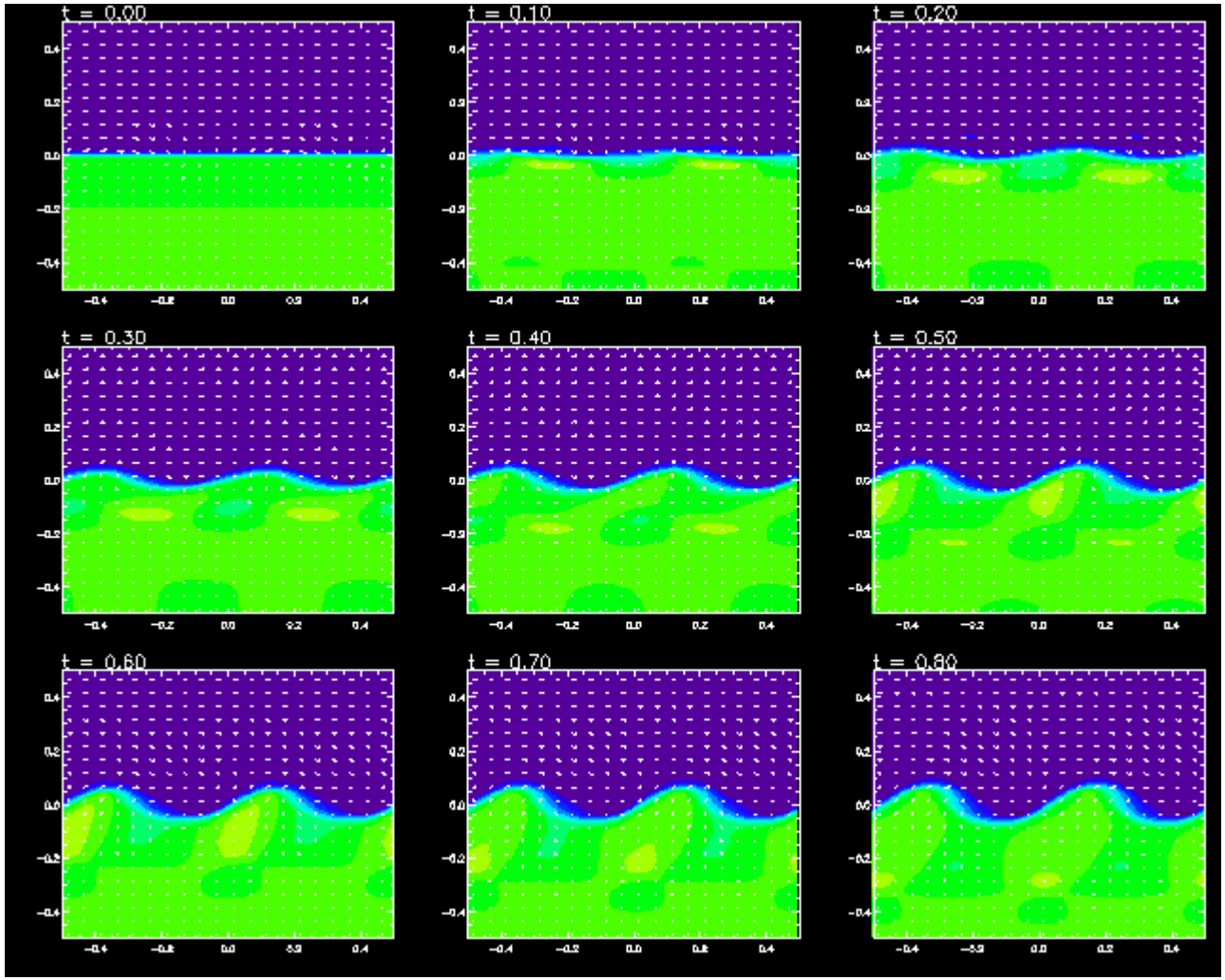
Velocity shear dependence of KHI growth rate

Vx=0.1



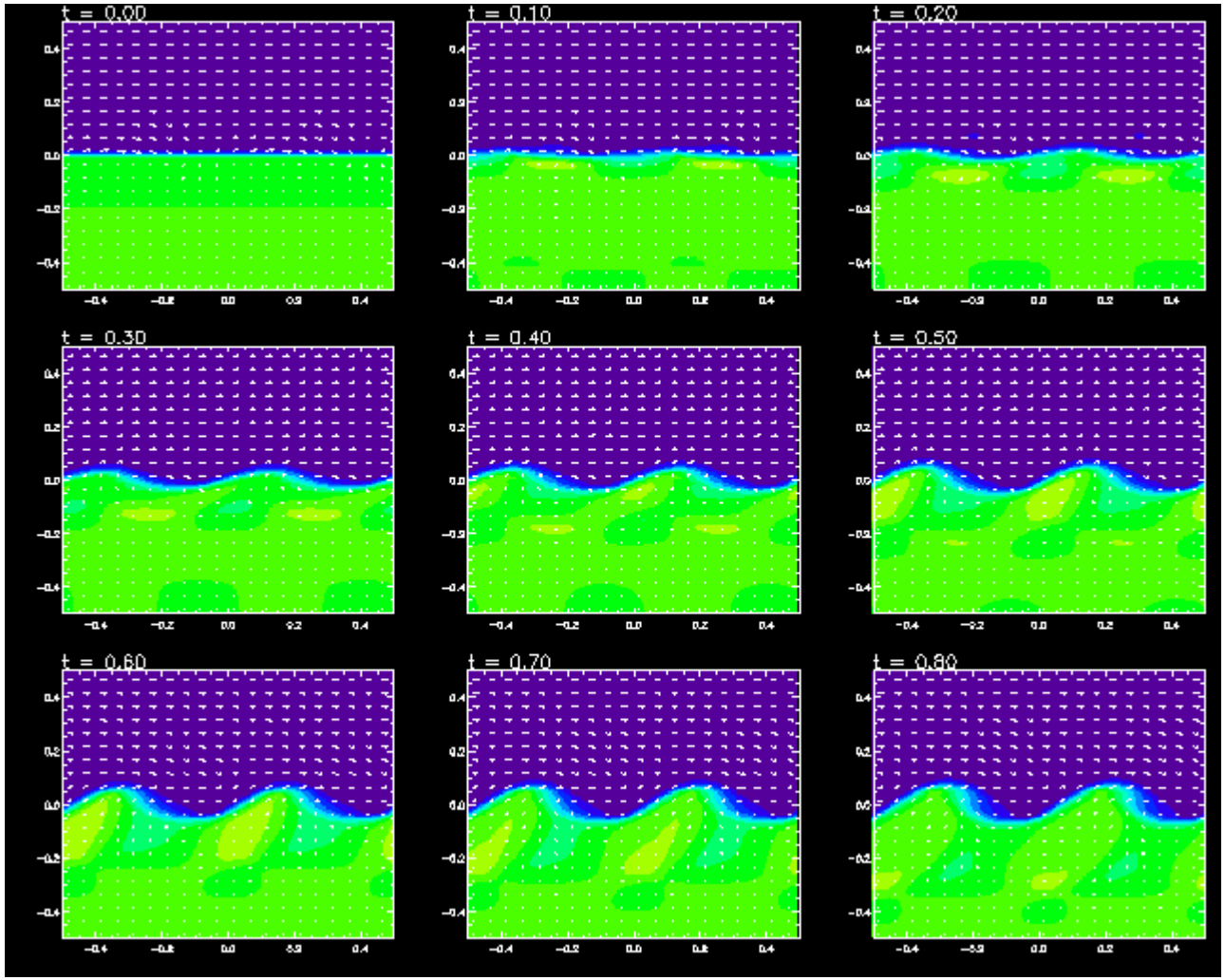
Velocity shear dependence of KHI growth rate

Vx=0.2



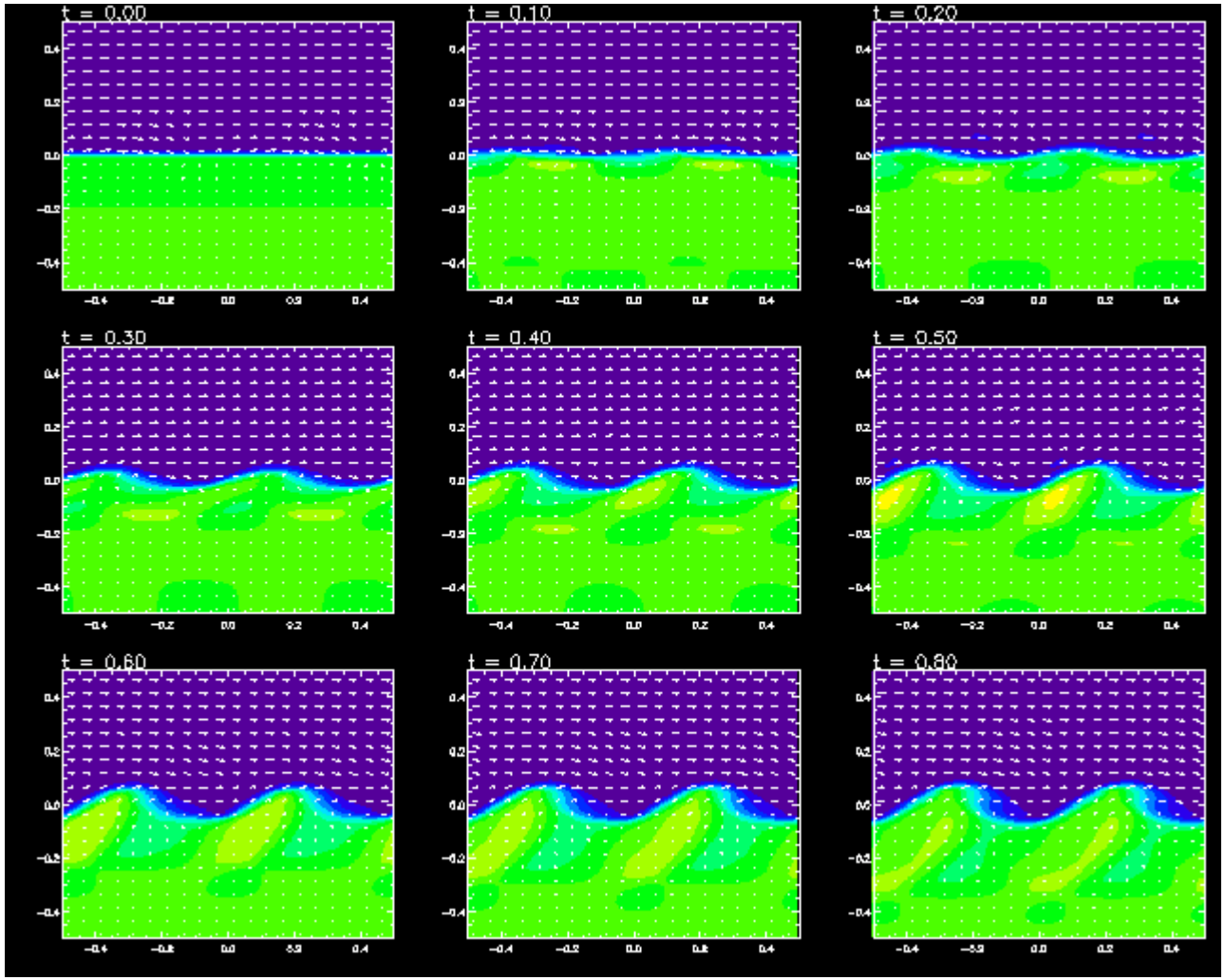
Velocity shear dependence of KHI growth rate

Vx=0.3



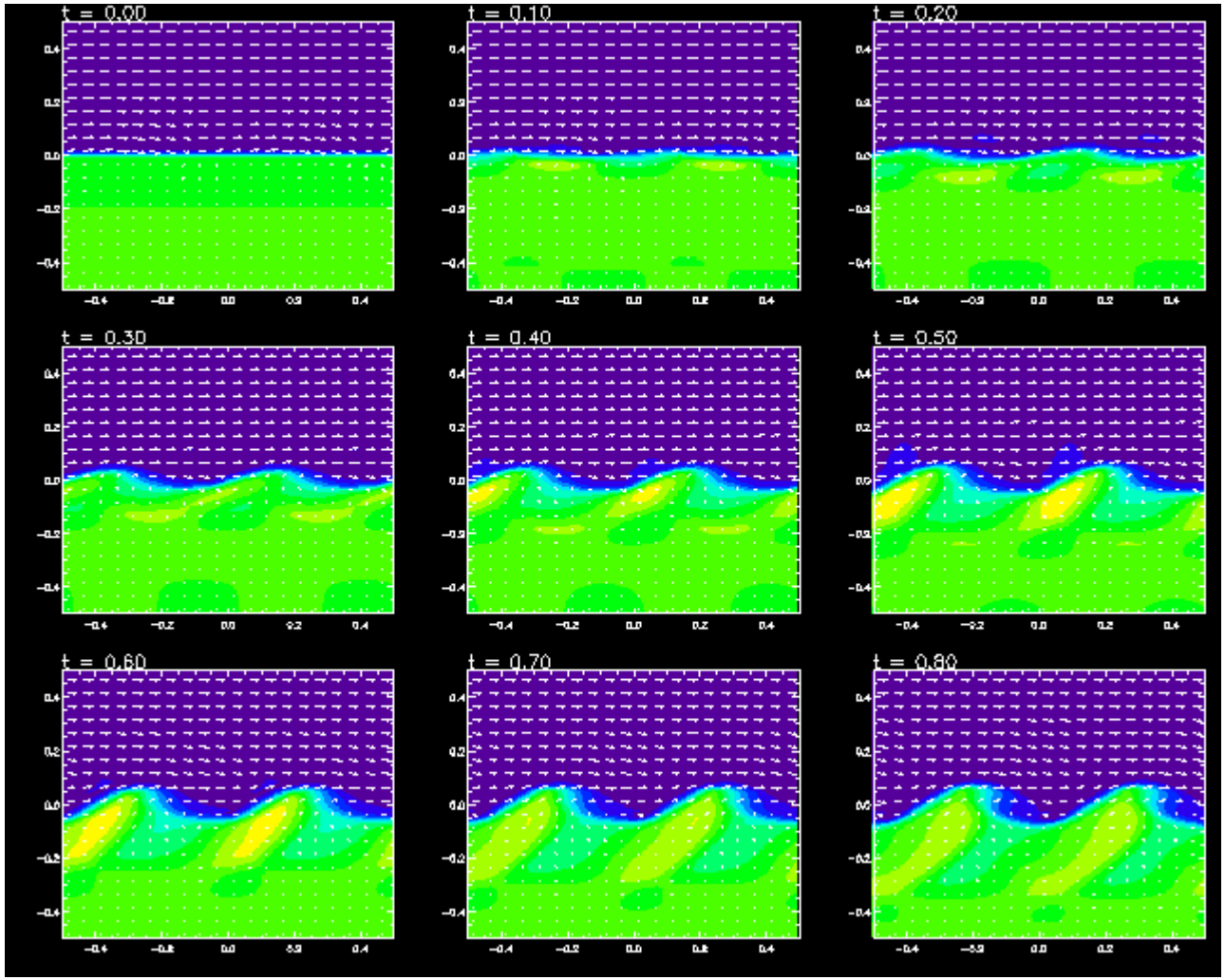
Velocity shear dependence of KHI growth rate

Vx=0.4



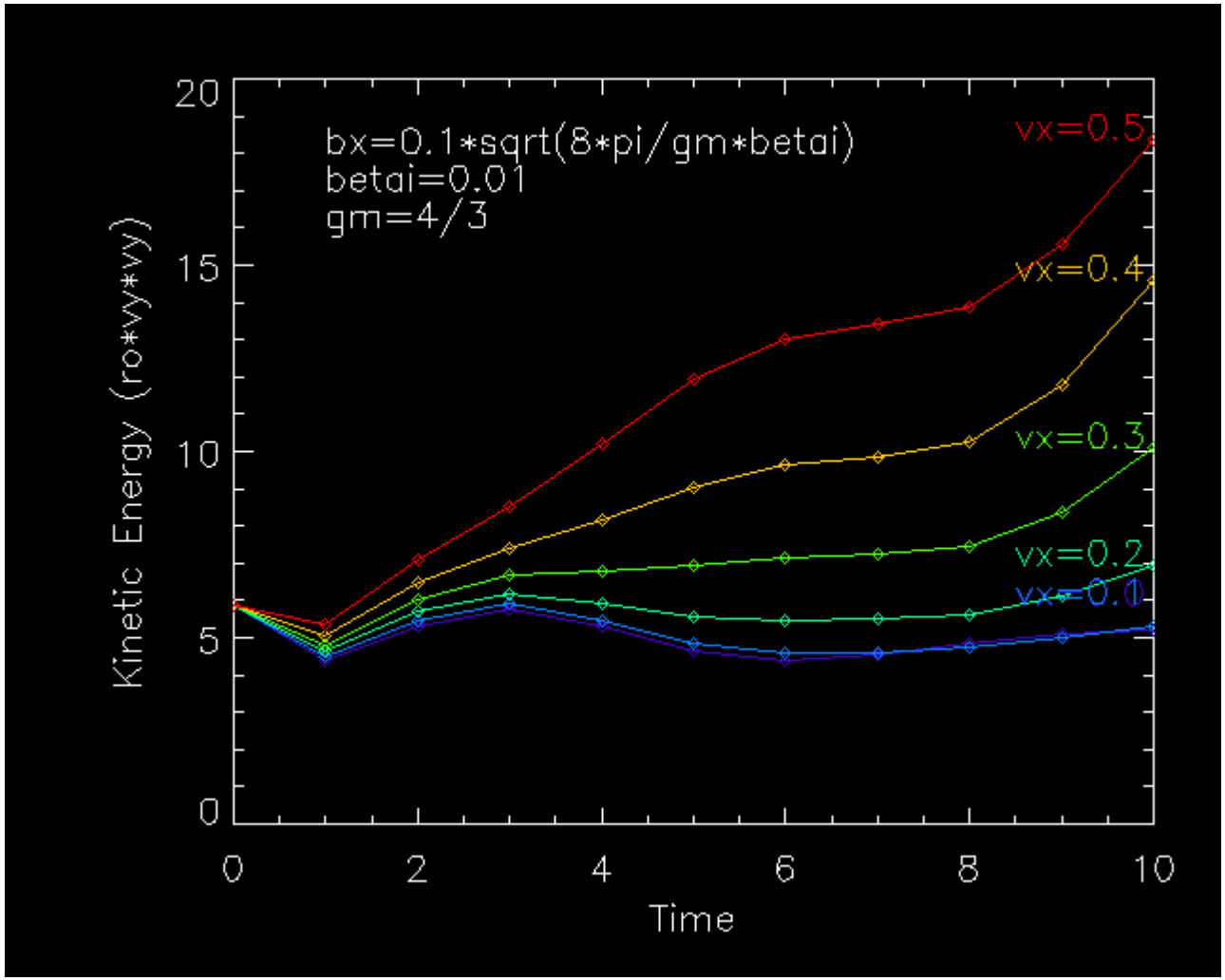
Velocity shear dependence of KHI growth rate

Vx=0.5



Velocity shear dependence of KHI growth rate

KHI growth


bx=0.1*sqrt(8*pi/gm*betai)
betai=0.01
gm=4/3
vx=0.5
vx=0.4
vx=0.3
vx=0.2
vx=0.1
Kinetic Energy (ro*vy*vy)
Time
0
5
10
15
20
0
2
4
6
8
10

Conclusions

- We performed relativistic MHD simulations using CANS 2D
- Jet
  - Morphology of Jet depending on B field
- Kelvin-Helmholtz Instabilities
  - Comparison with MHD
    - B field dependence
  - Parametric survey
    - Velocity shear dependence