Impact of Hall MHD on the evolution of 3D complex magnetic structures

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Order analysis of dimensionless induction equation tell us that the Hall effects are important while studying the reconnection in astrophysical plasma, particularly solar coronal plasma.

$$\boxed{\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v}_i \times \mathbf{B}) - \left(\frac{1}{S}\right) \nabla \times \mathbf{J} - \left(\frac{\delta_i}{L}\right) \nabla \times (\mathbf{J} \times \mathbf{B})}$$

Advection Diffusion Hall term

where $\boldsymbol{J} = (\nabla \times \boldsymbol{B})/\mu_0$ is the current density (J~B/L) at large length scales (**L~10^6 m, S= (L v_A/η) ~10^{12}**), **J** is very small, and (1/S)~10^{-12}

For solar coronal reconnection : L ~ 32 m, S = 10^7, δ_i ~ 2.25 m (Priest & Forbes, 2000)

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v_i} \times \boldsymbol{B}) - \underbrace{\frac{1}{S}}_{10^{-7}} \nabla^2 \boldsymbol{B} - \underbrace{\frac{\delta_i}{L}}_{10^{-2}} \nabla \times (\nabla \cdot \boldsymbol{BB})$$

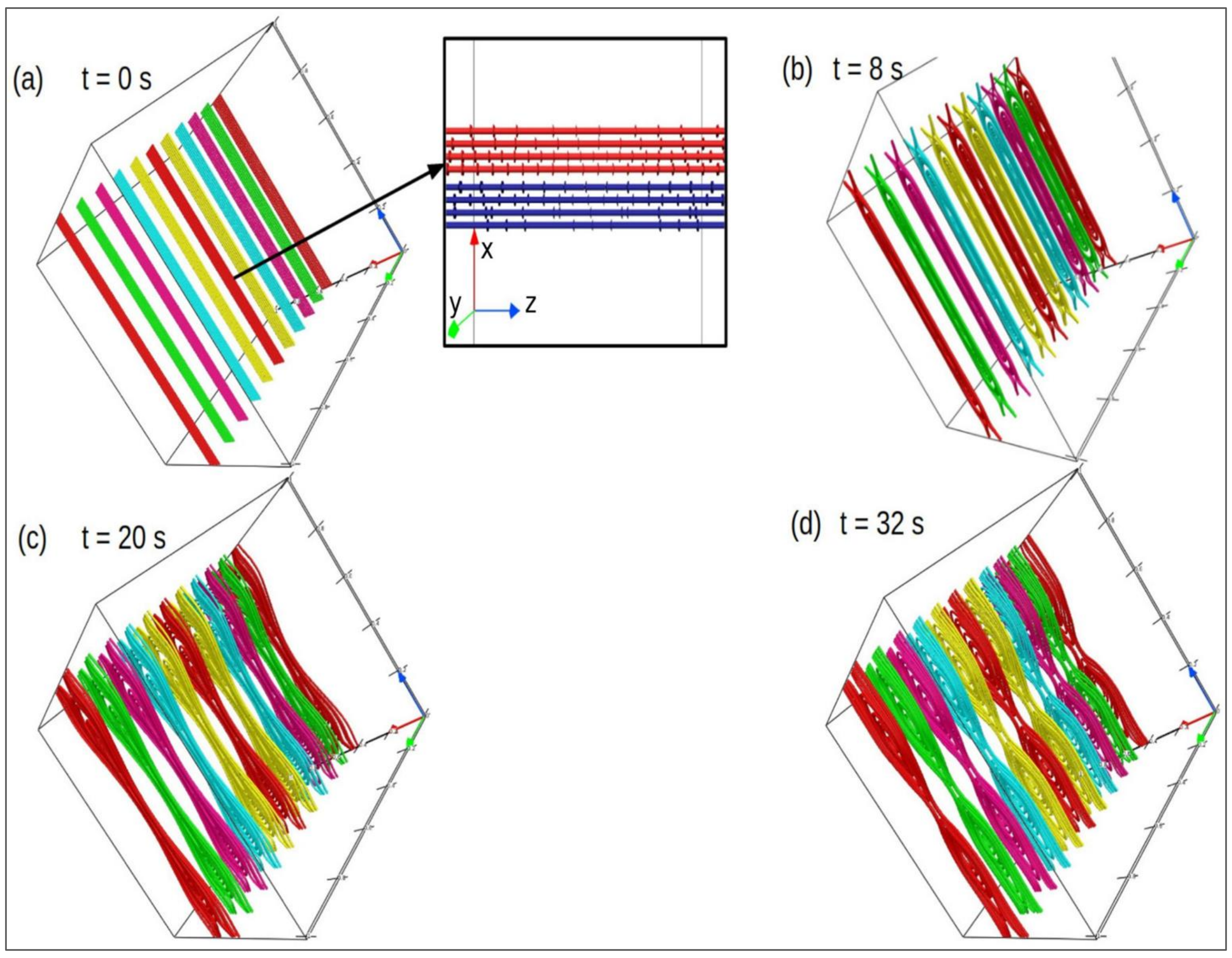

Figure 1. Evolution of magnetic field lines during MHD simulation for sinusoidal initial condition.

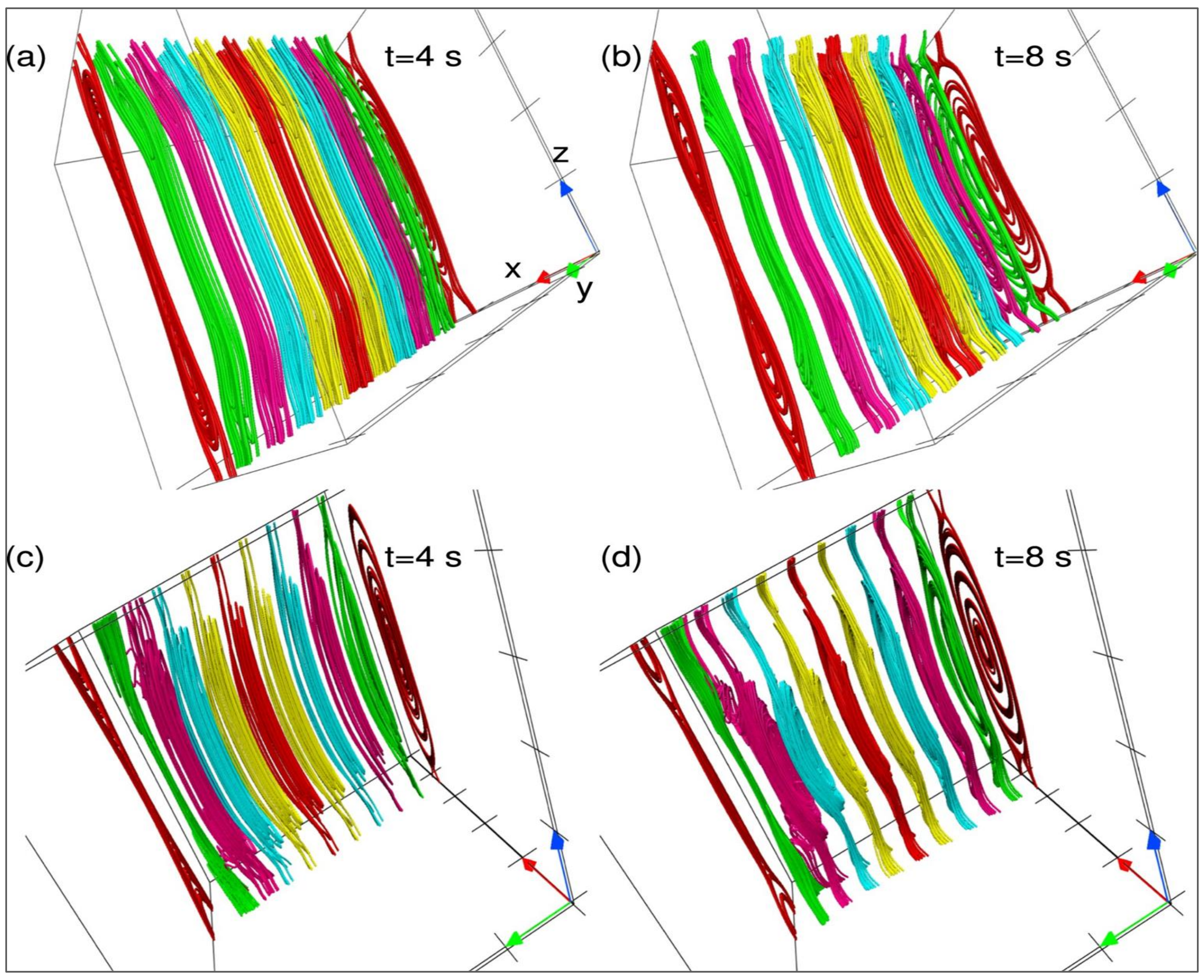

Figure 2. Evolution of magnetic field lines during HMHD simulation for sinusoidal initial condition.

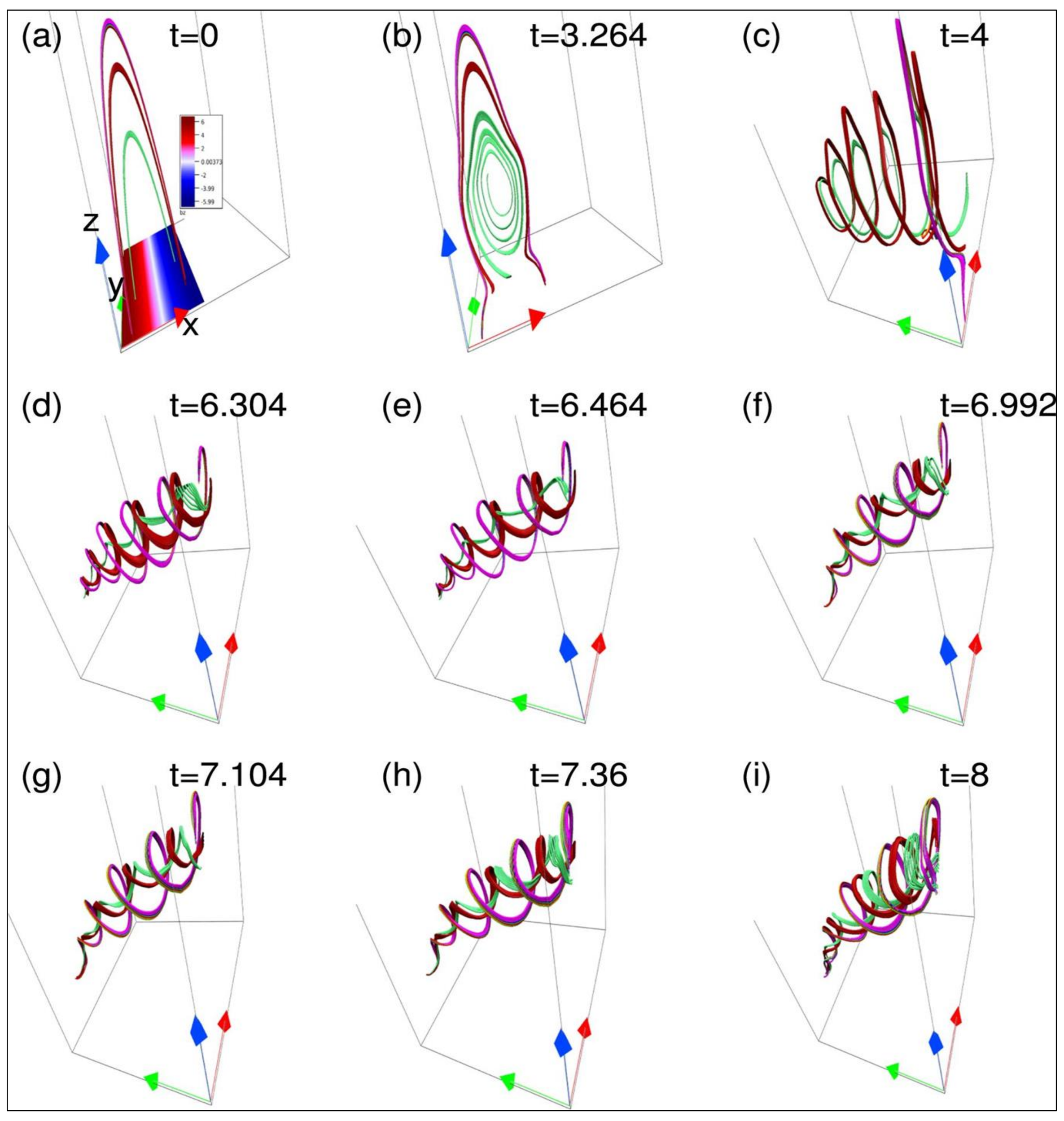

Figure 3. Evolution of solar-like flux rope during MHD simulation.

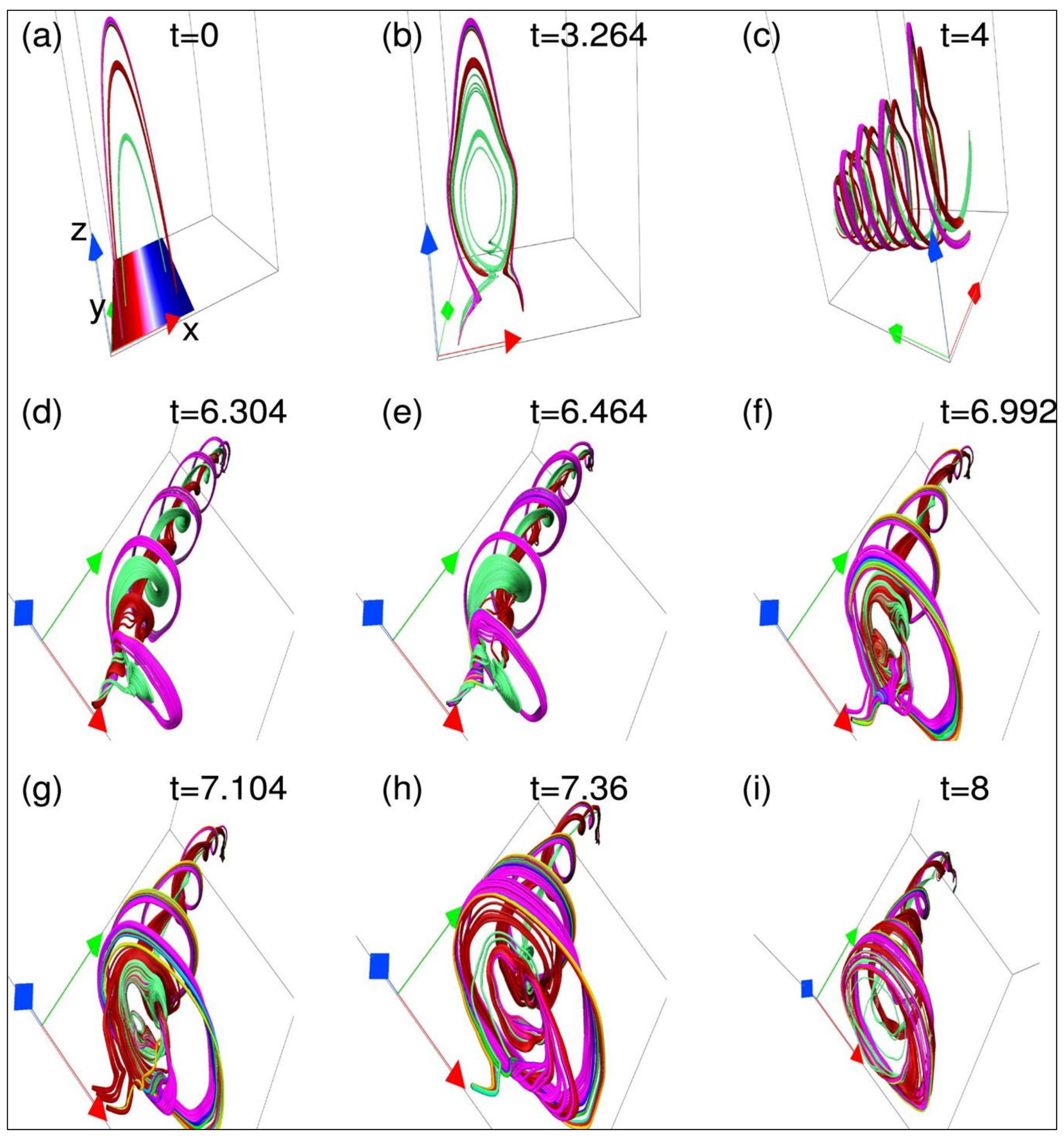

Figure 4. Evolution of solar-like flux rope during HMHD simulation.

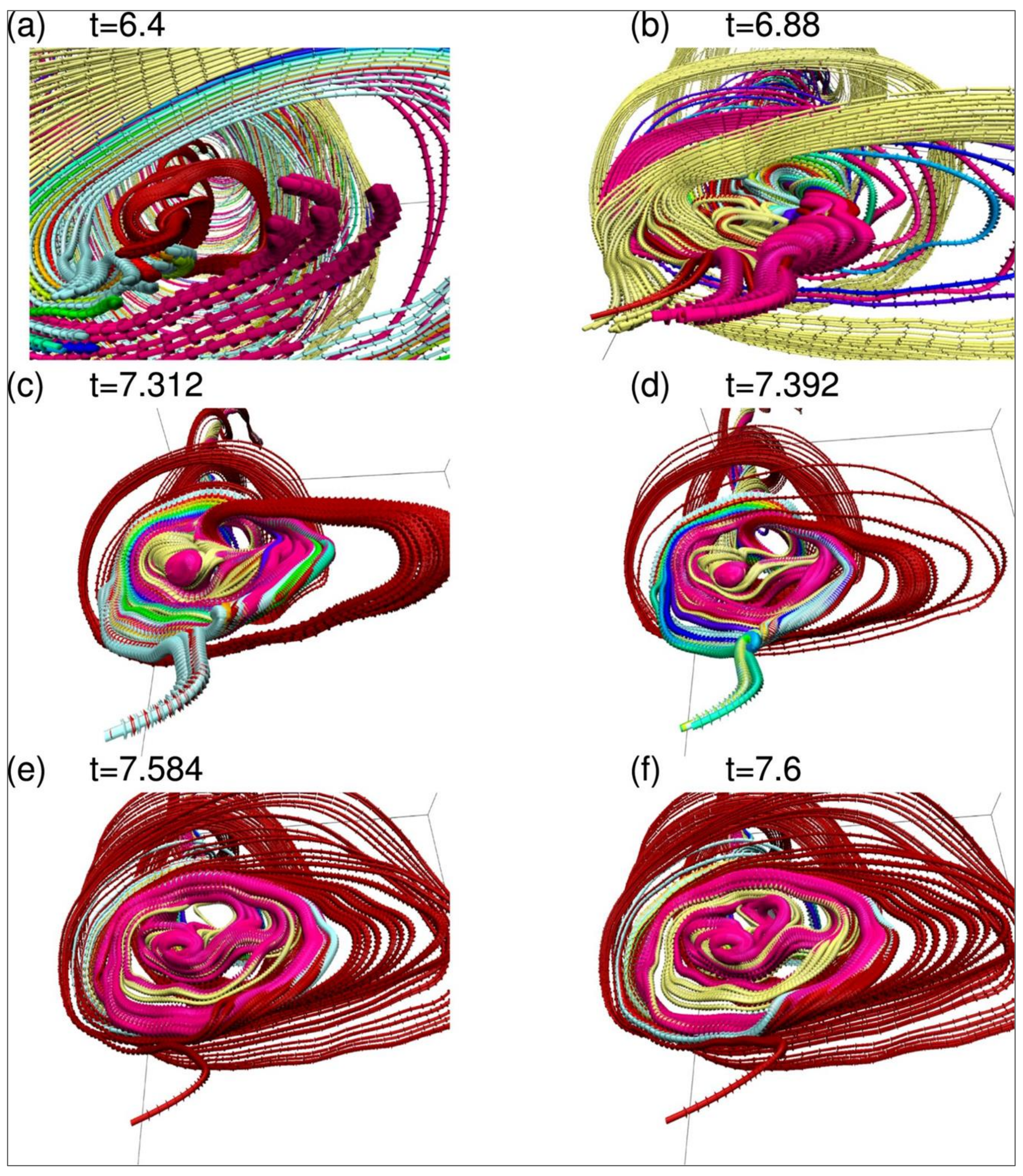

Figure 5. Zoomed view of complex internal reconnection during HMHD simulation of flux rope.

Results:
1. Hall effects are important only around reconnection regime or where the sharp gradient of magnetic field exist.
2. Hall MHD is giving faster reconnection compared to the MHD evolution.
3. Small scale changes affect the large/global scale through a series of complex magnetic reconnection in Hall MHD

Ref.- **K.Bora et al. 2021 ApJ906 102**