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The relation between a flux rope eruption (plasmoid ejection) and magnetic reconnection in solar flares

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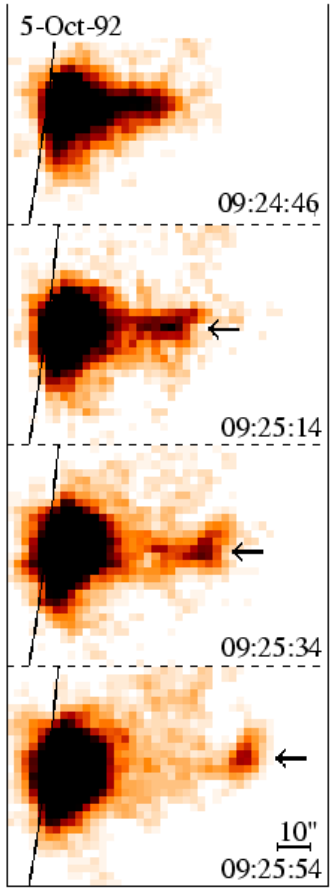
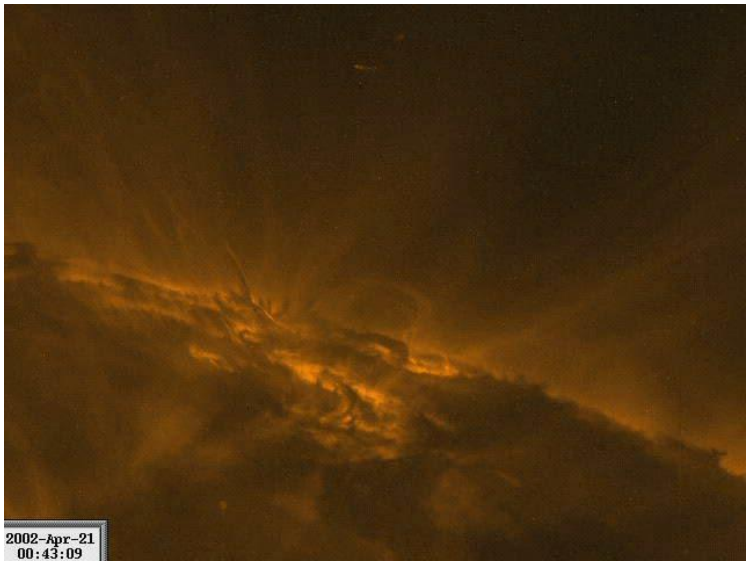
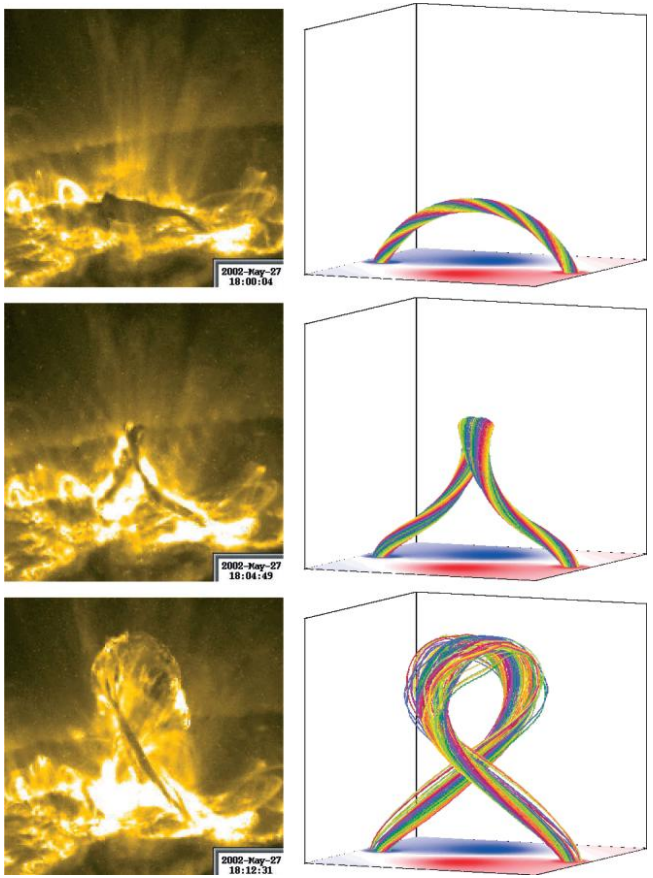
Outline of this talk

1. Introduction
   - The role of plasmoid in magnetic reconnection
2. Numerical experiment of plasmoid-induced reconnection model in 2D
3. Numerical experiment of plasmoid-induced reconnection model in 3D
4. Conclusions

Plasmoid (filament eruption) in solar flares







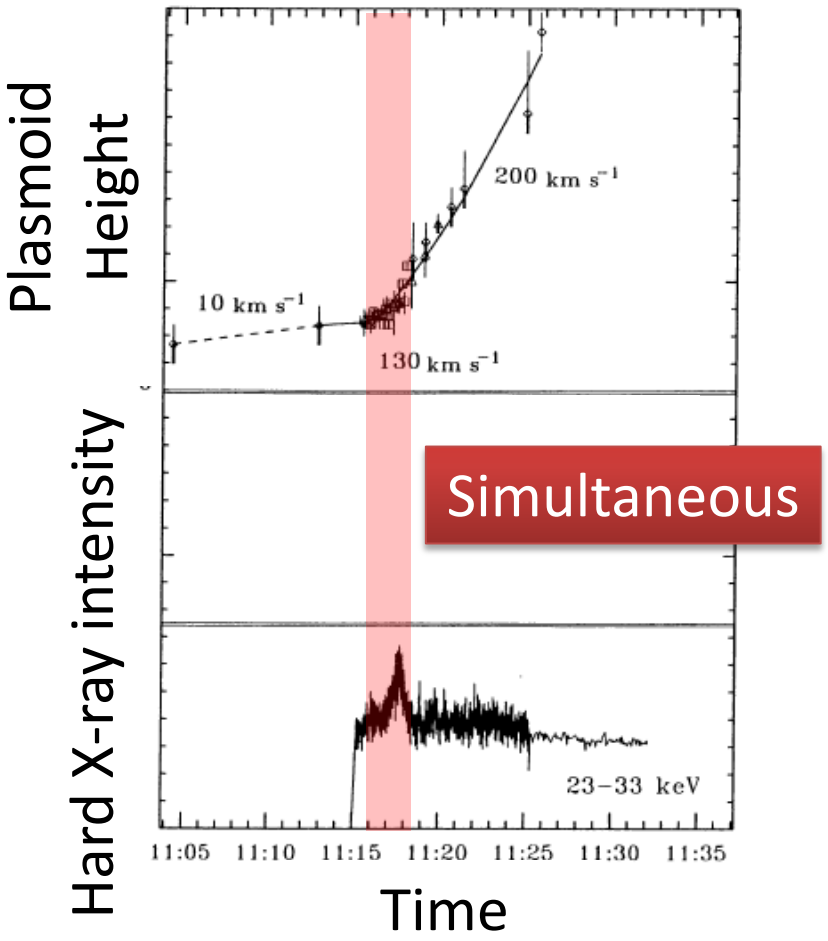
Oct 5, 1992 flare
Yohkoh/Soft X-ray Telescope
(Ohyama & Shibata 1998)

April 21, 2002 flare
TRACE 195Å EUV
(McKenzie & Savage 2009)

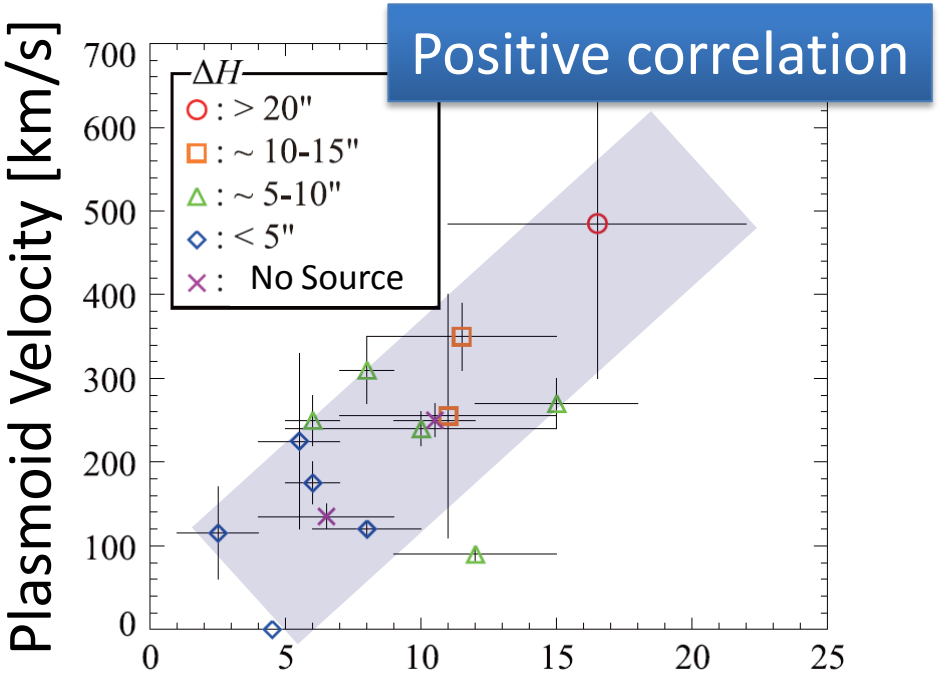
May 27, 2002 flare
TRACE observation and modeling
(Torok & Kliem 2005)

Relation between plasmoid ejection and magnetic reconnection

Observation with Yohkoh
(Ohyama & Shibata 1997)



Observation with Yohkoh
(Shibata 1995, Shimizu et al. 2008)

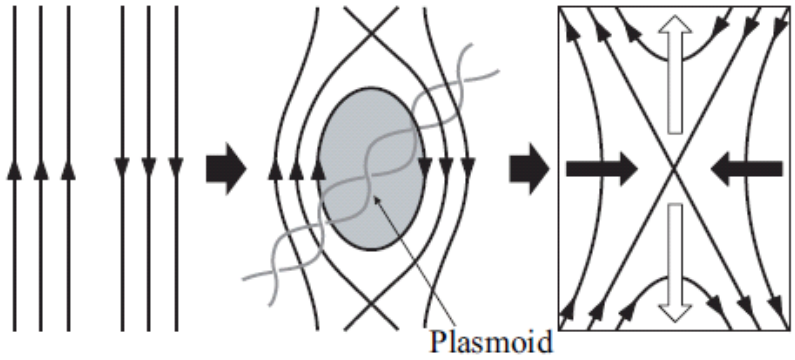


Roles of the Plasmoid

(Plasmoid-induced reconnection model)

(Shibata & Tanuma 2001)

(1) To store energy by inhibiting reconnection



Plasmoid inhibits reconnection

↓

Energy is stored

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When plasmoid is ejected, energy is released suddenly

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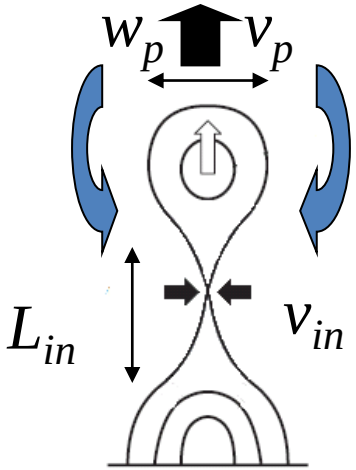
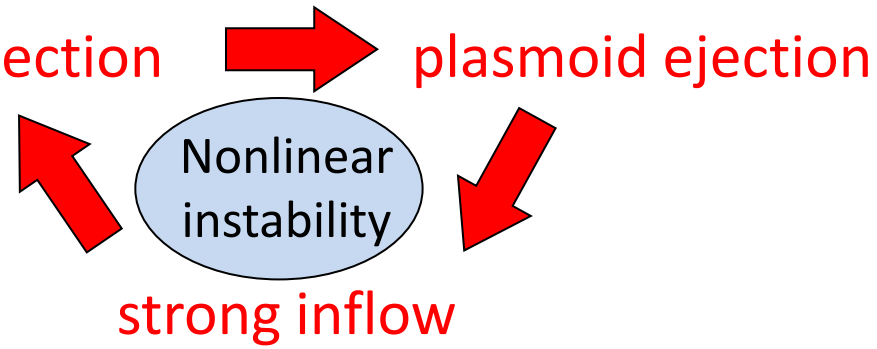
(2) To induce strong inflow into reconnection region

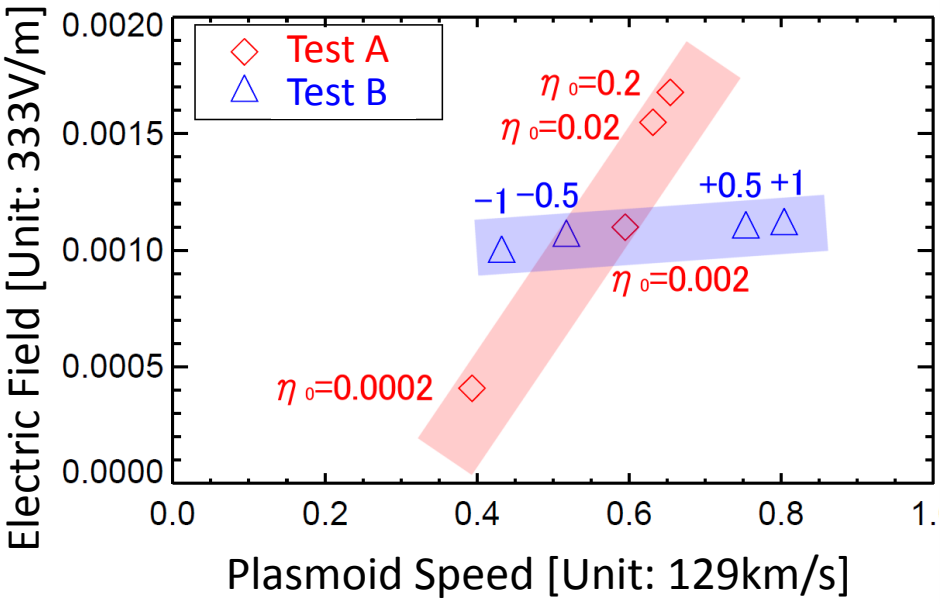


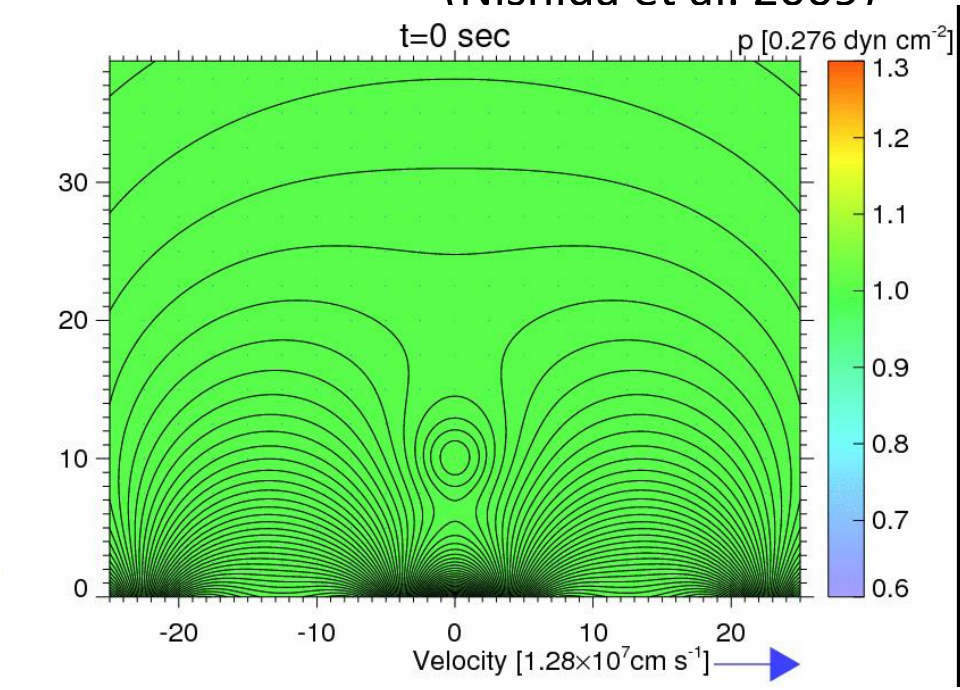
$$v_{in} = \frac{w_p}{L_{in}} v_p$$



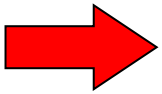
Examination of plasmoid-induced reconnection model with 2D MHD model

(Nishida et al. 2009)





Control plasmoid speed and reconnection speed Individually

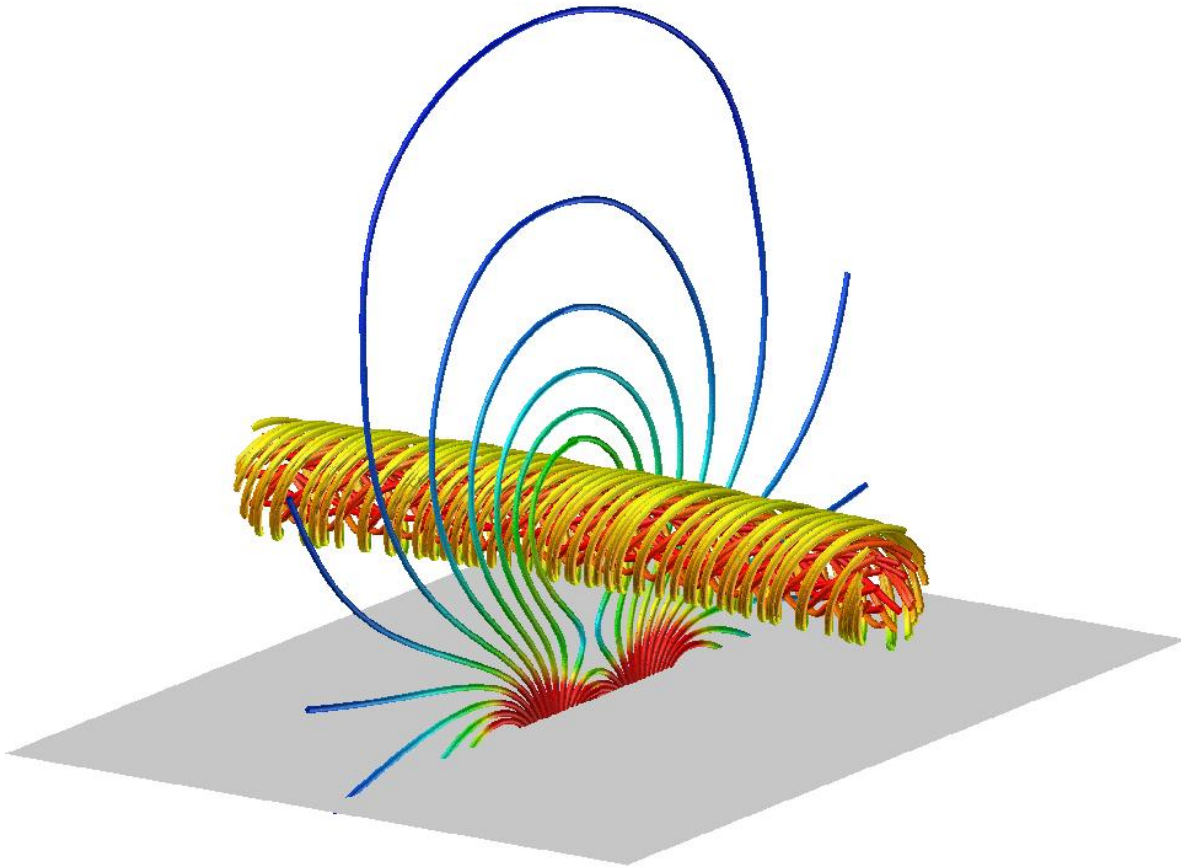


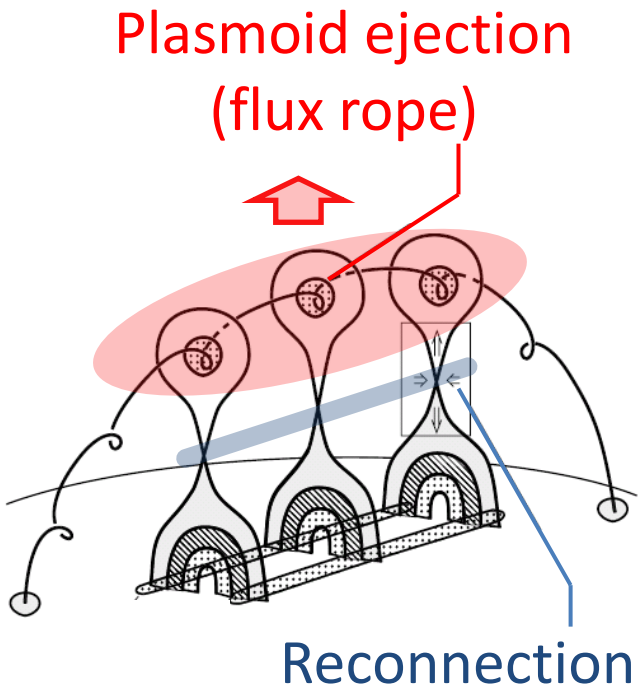
Positive correlation between plasmoid speed and reconnection speed

How about in 3D?

Examination of plasmoid-induced reconnection model with 3D MHD model

Simply extend to 3D (# of grids: 400^3)

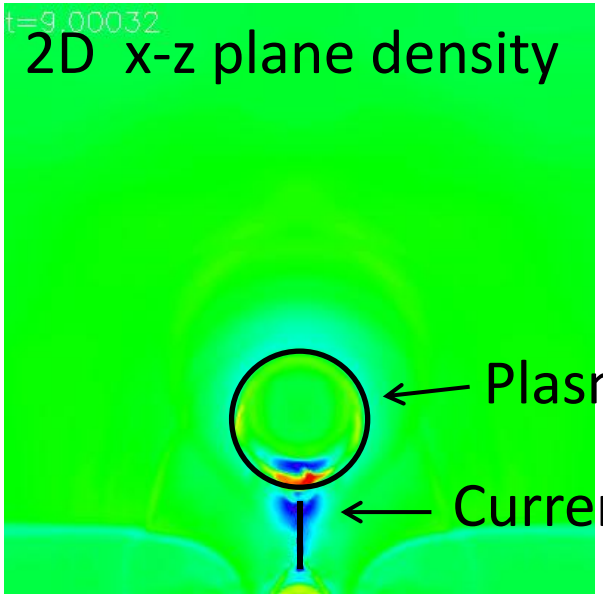


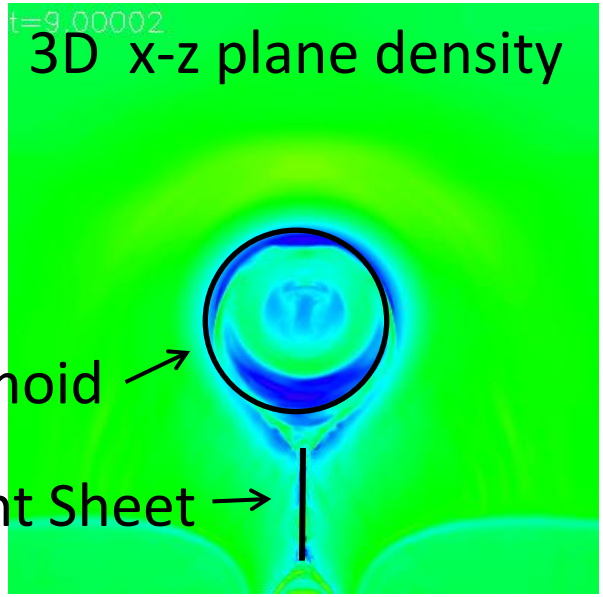


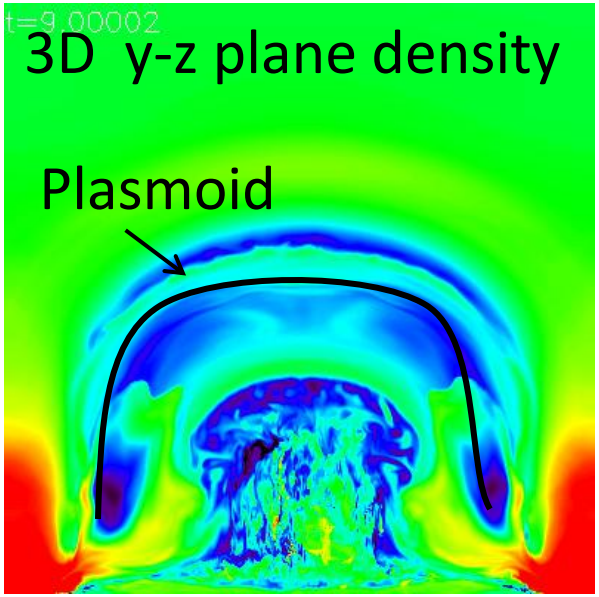
(Figure from Shiota et al. 2005)

Plasomid is lifted up by kink instability faster than 2D

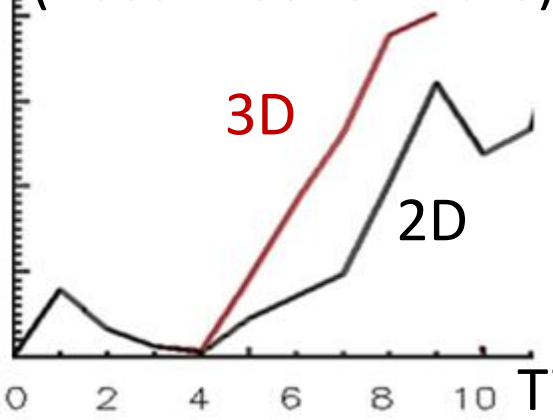
2D vs. 3D



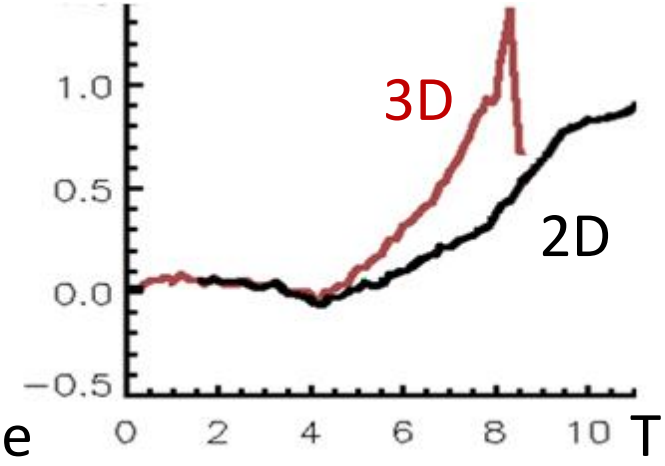




Electric Field
(Reconnection Rate)



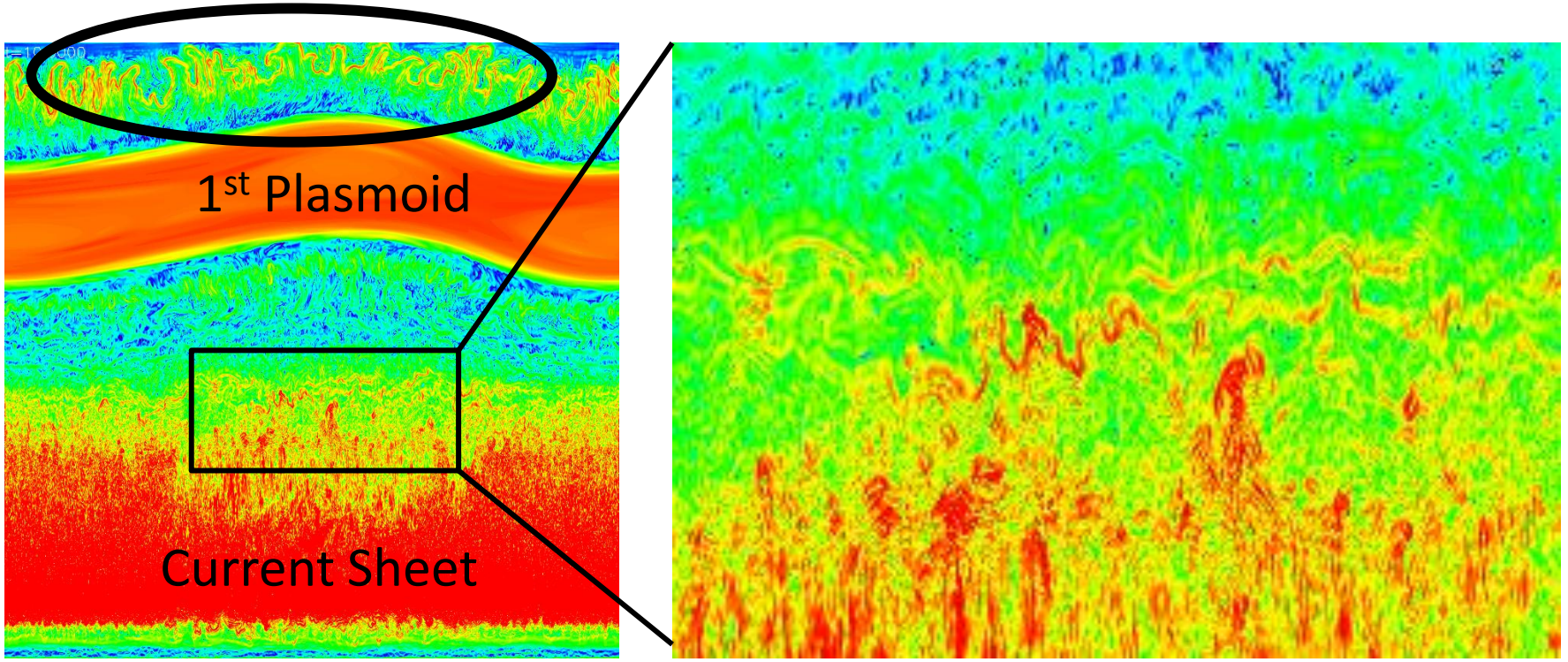
Plasmoid Speed



Consistent with plasmoid-induced-reconnection model

Turbulent structure in 3D current sheet (# of grids = 800^3)

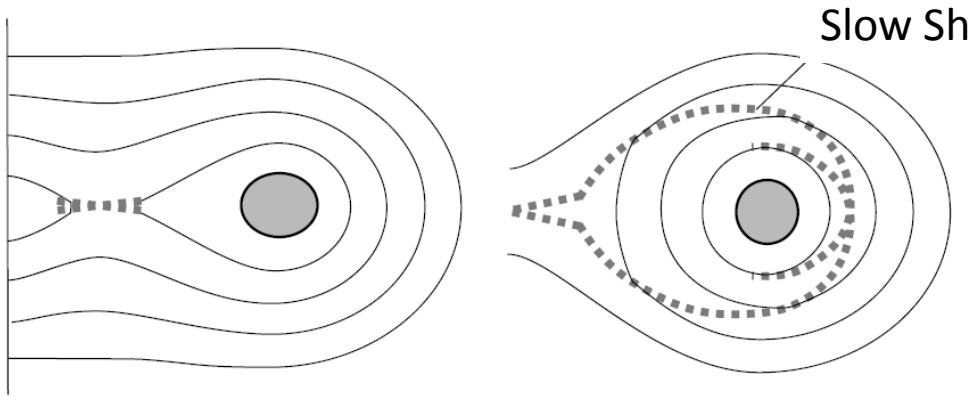
y-z plane current density



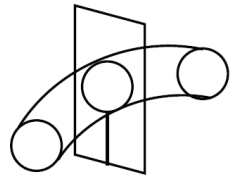
Filament-like secondary plasmoids are created in the current sheet

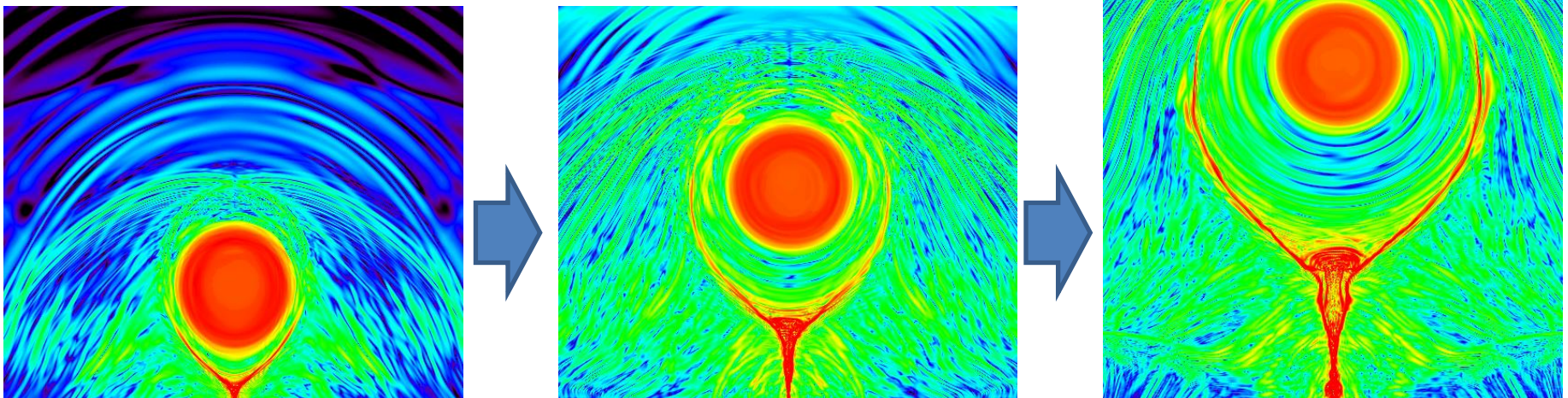
Structure at top of plasmoid

Step 1: Show shock front extend into top of the plasmoid



Shiota et al. (2005)

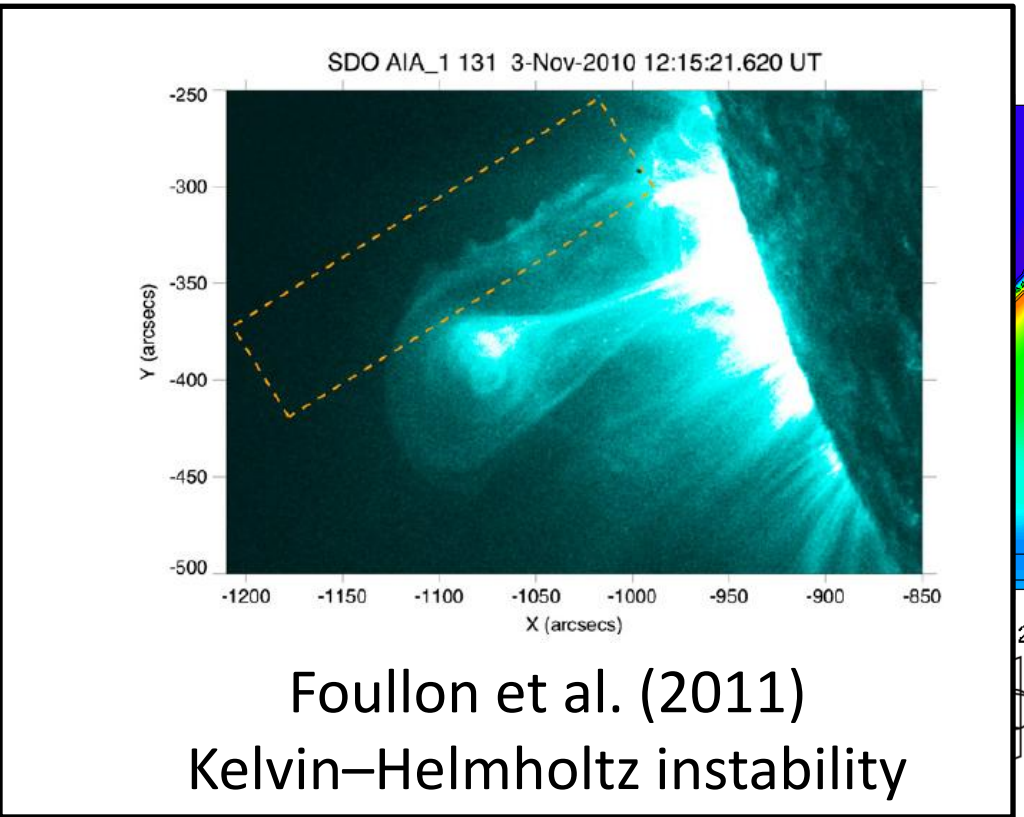




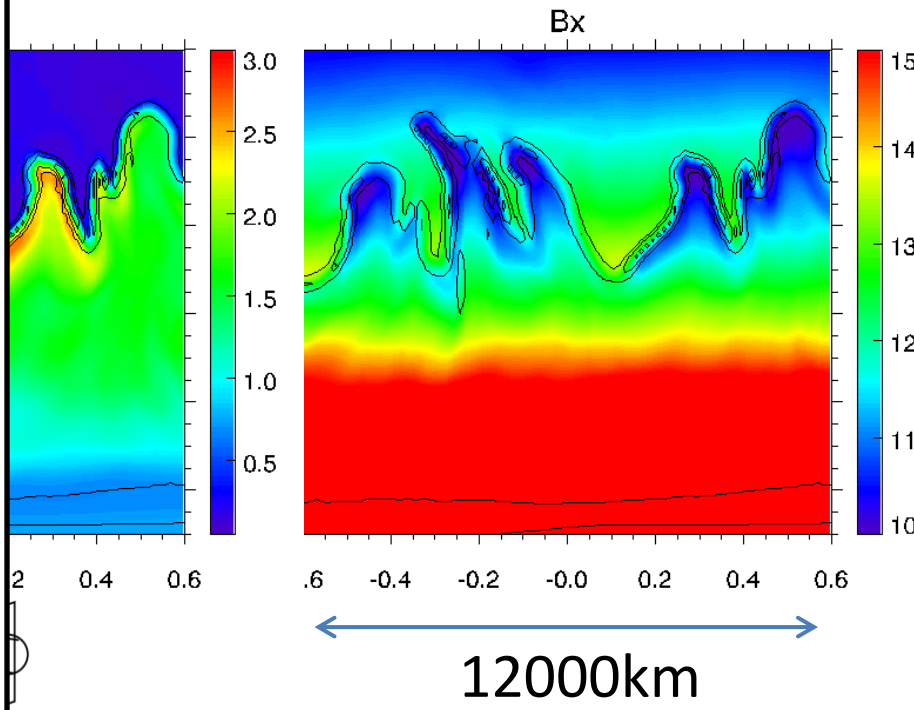
Structure at top of plasmoid

Step 2: Rayleigh–Taylor instability at the top of the plasmoid

Size ~ 1000-2000km



Foullon et al. (2011)
Kelvin–Helmholtz instability

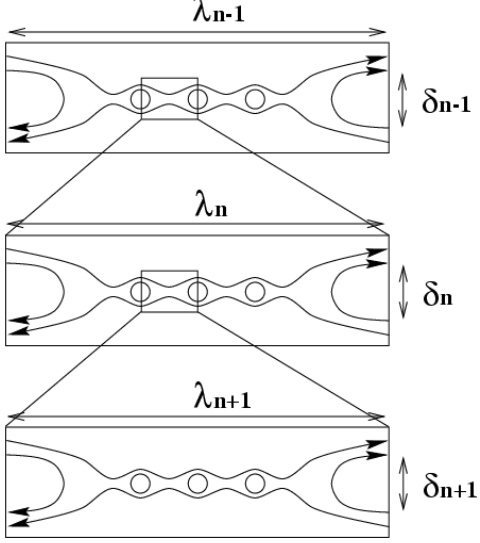


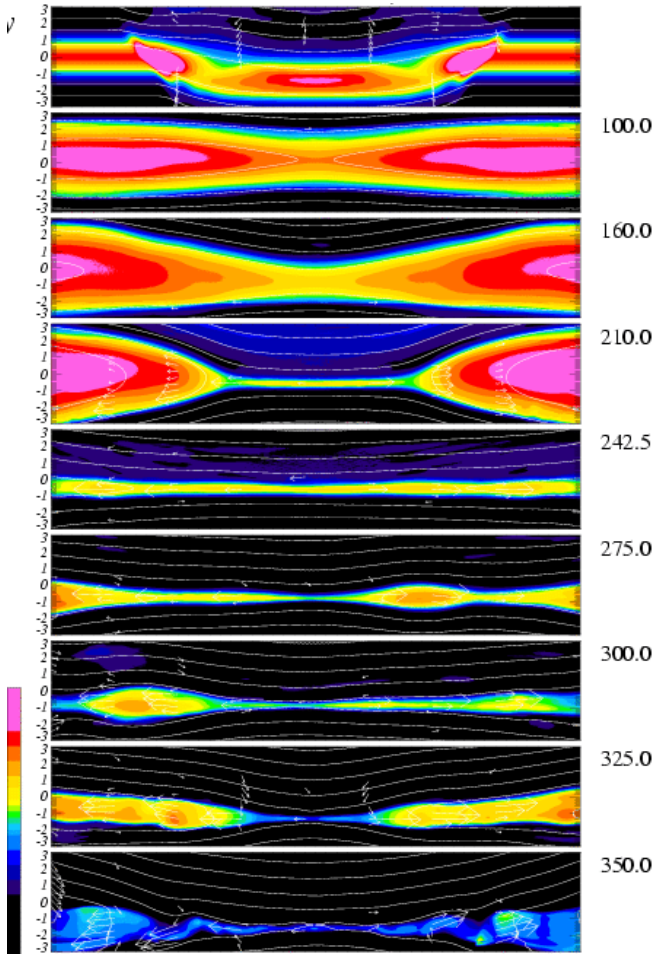
12000km

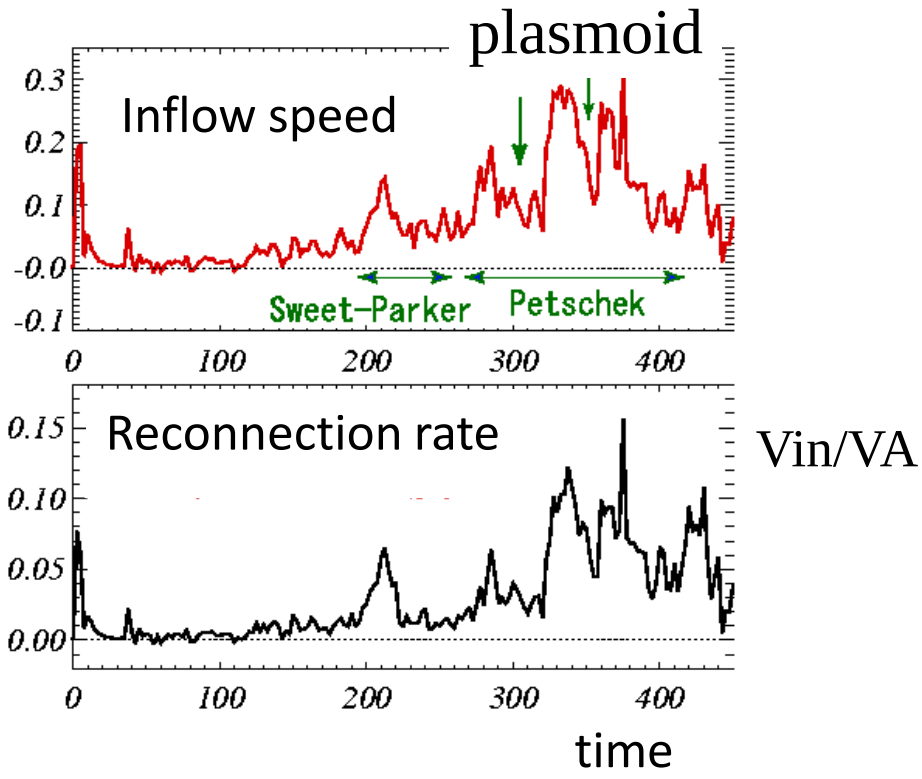
Conclusion

- We performed 2D/3D resistive MHD simulations of a plasmoid (flux rope) ejection in a solar flare.
- 2D examination
  - Positive feedback between plasmoid and reconnection.
- 3D examination
  - Many small plasmoids (flux ropes)
  - Evolution in 3D is faster than 2D case.
  - structure at top of plasmoid by Rayleigh–Taylor instability
- Results are consistent with plasmoid-induced reconnection model

What determines the speed of reconnection (energy release rate) ?

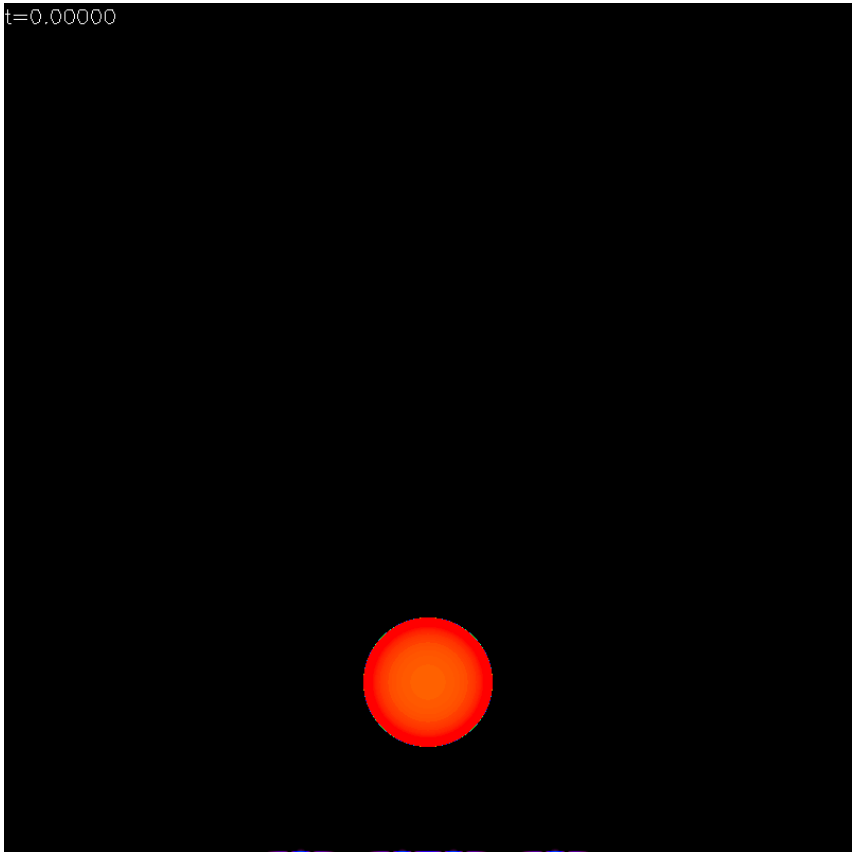


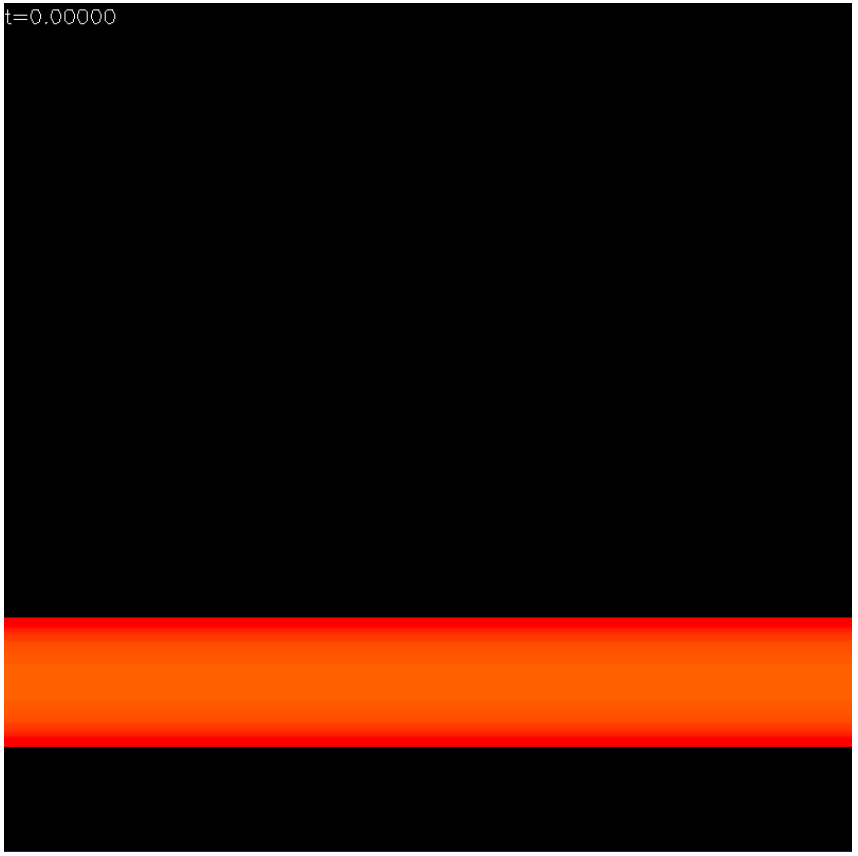


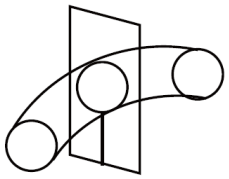


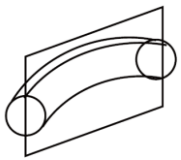
(Tanuma et al. 2001, Shibata and Tanuma 2001)

Electric current t=0 [sec]



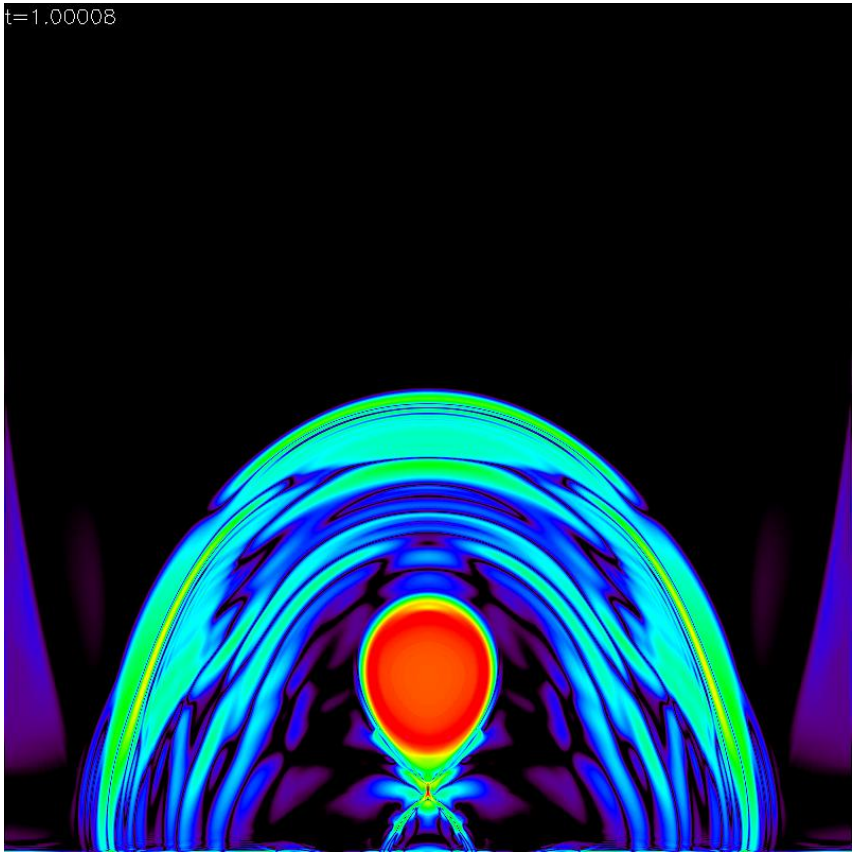


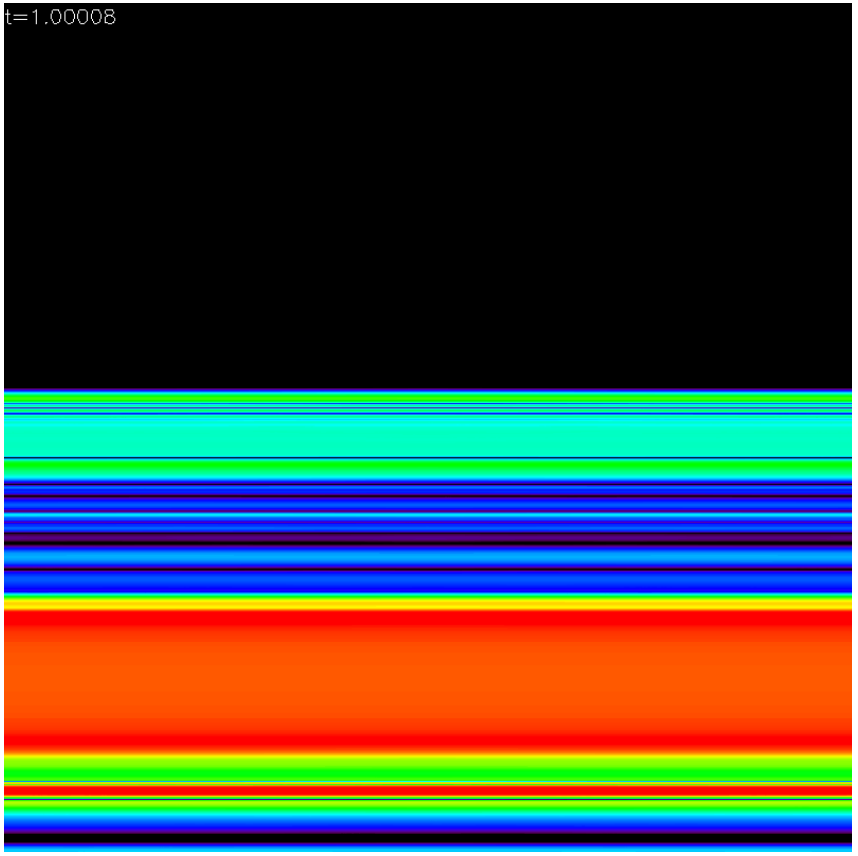


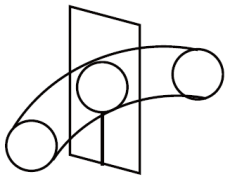


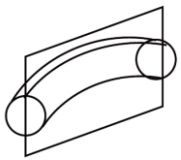
Electric current t=86 [sec]

Fast mode wave is propagating …



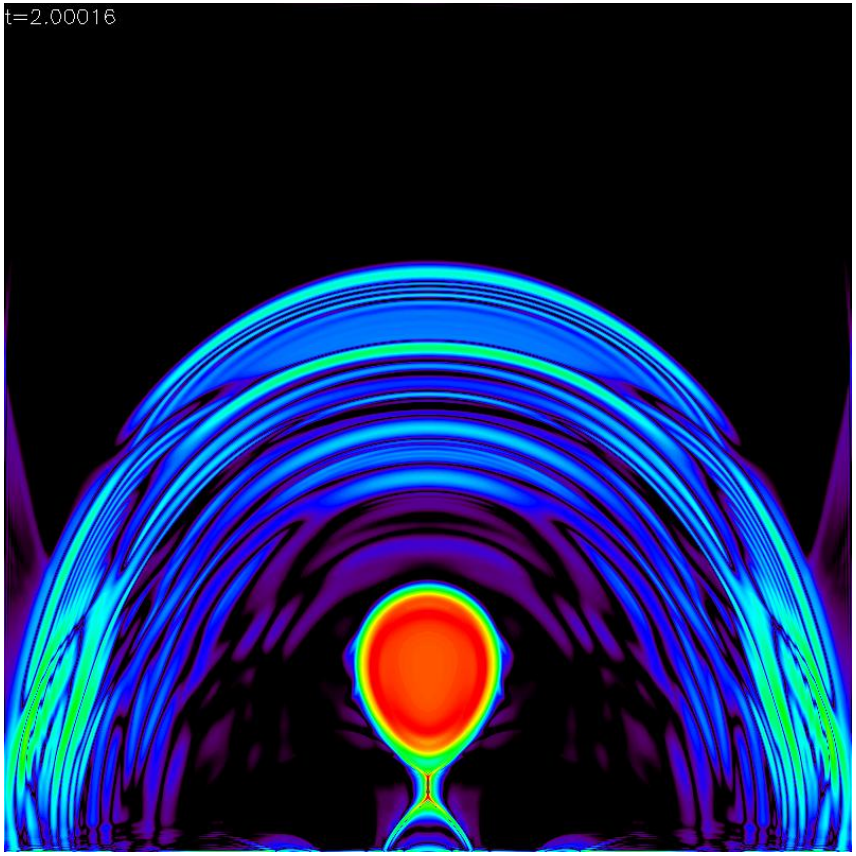


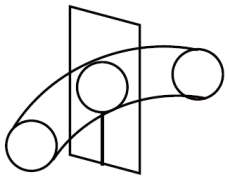


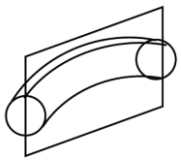


Electric current t=171 [sec]

Fast mode wave is propagating …

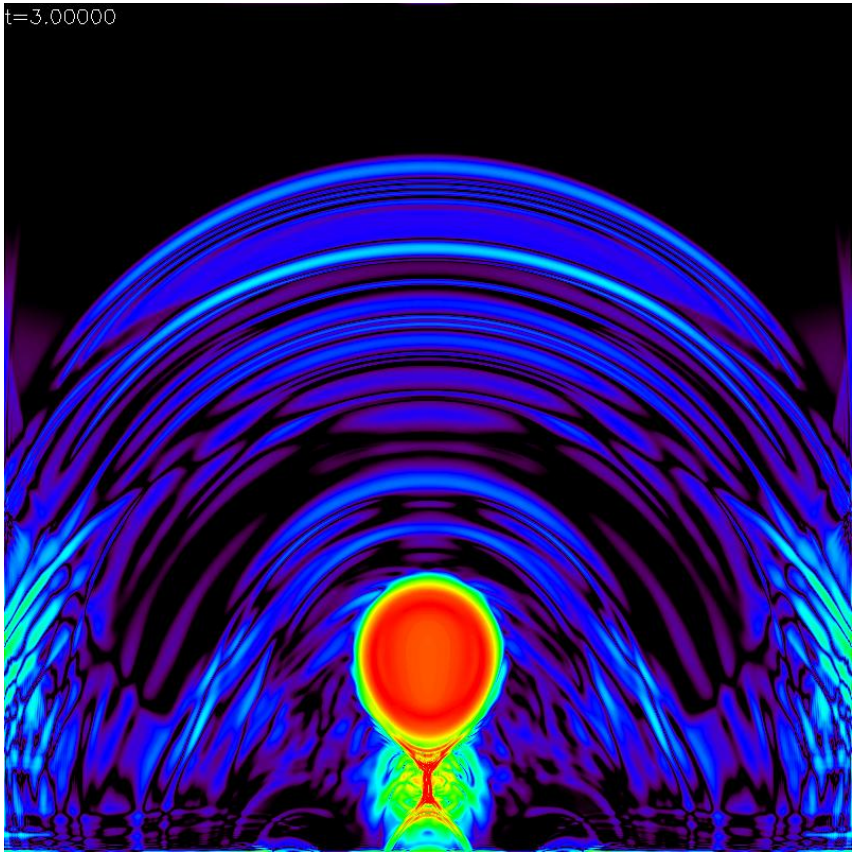


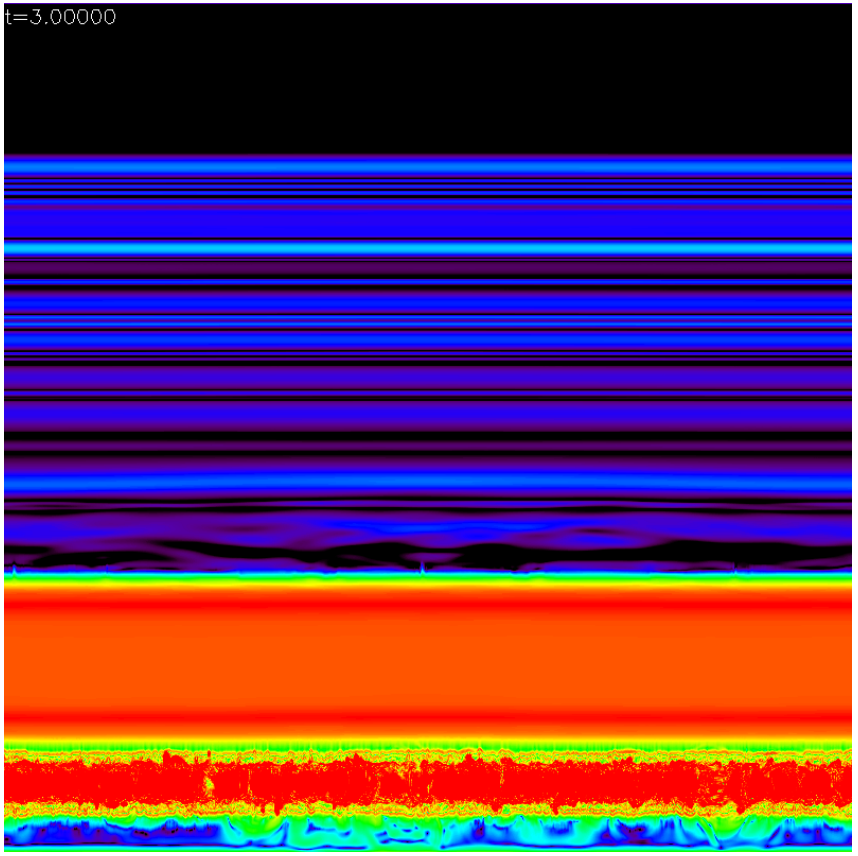


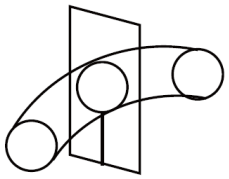


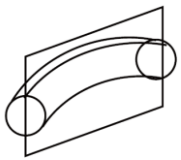
Electric current t=257 [sec]

Reconnection is starting …



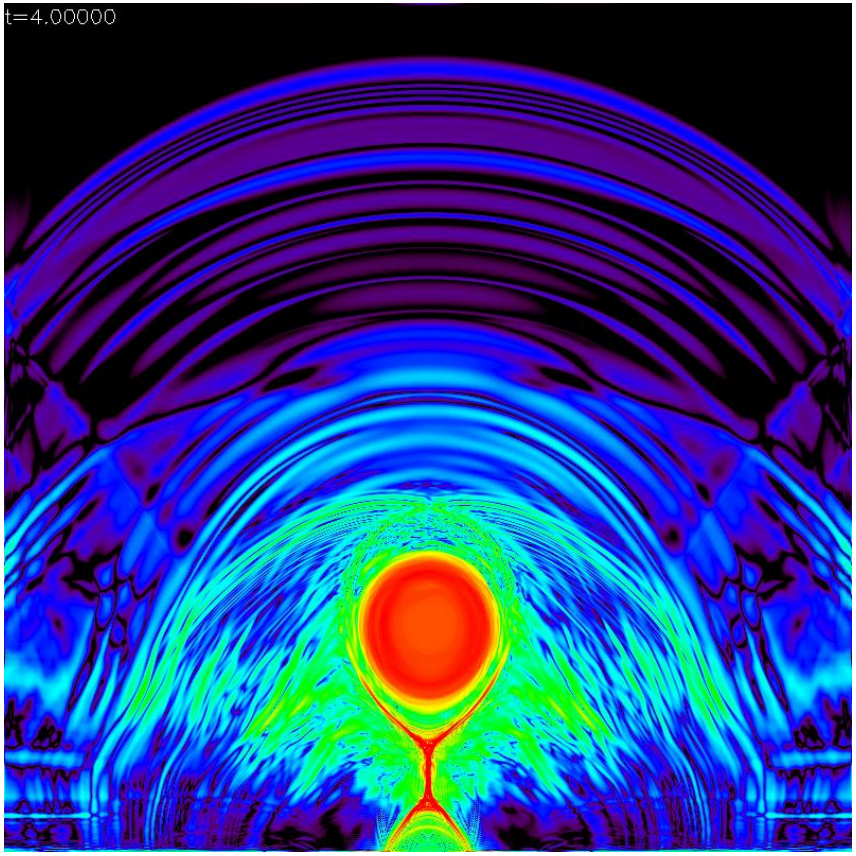


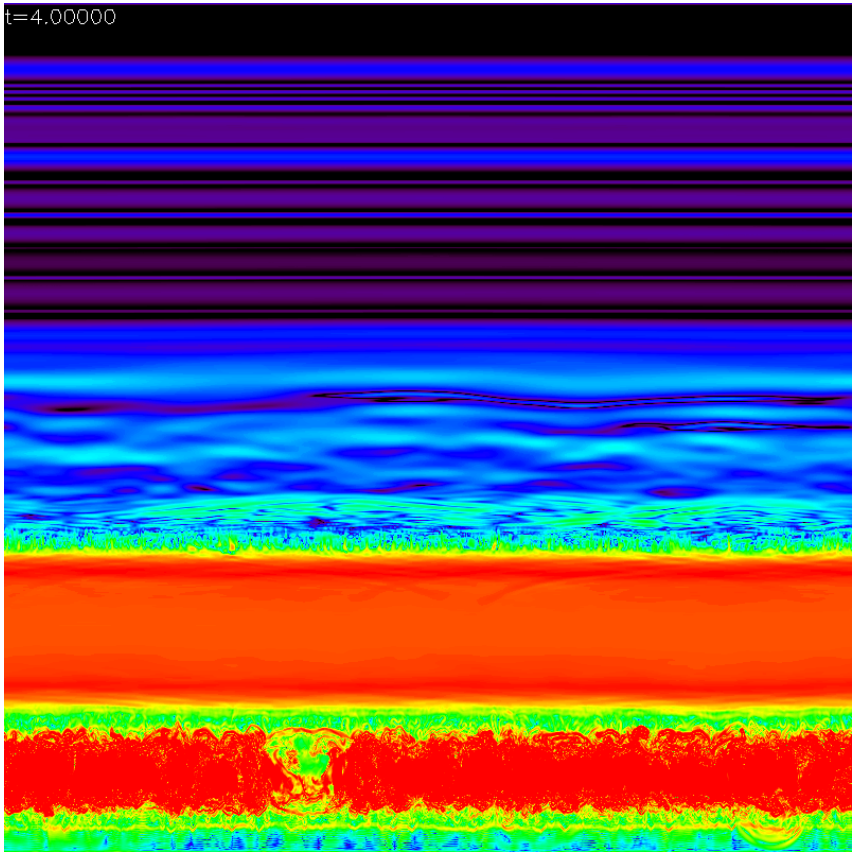


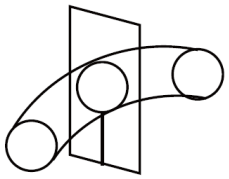


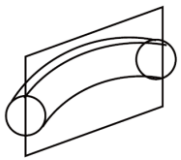
Electric current t=342 [sec]

Reconnection is starting …

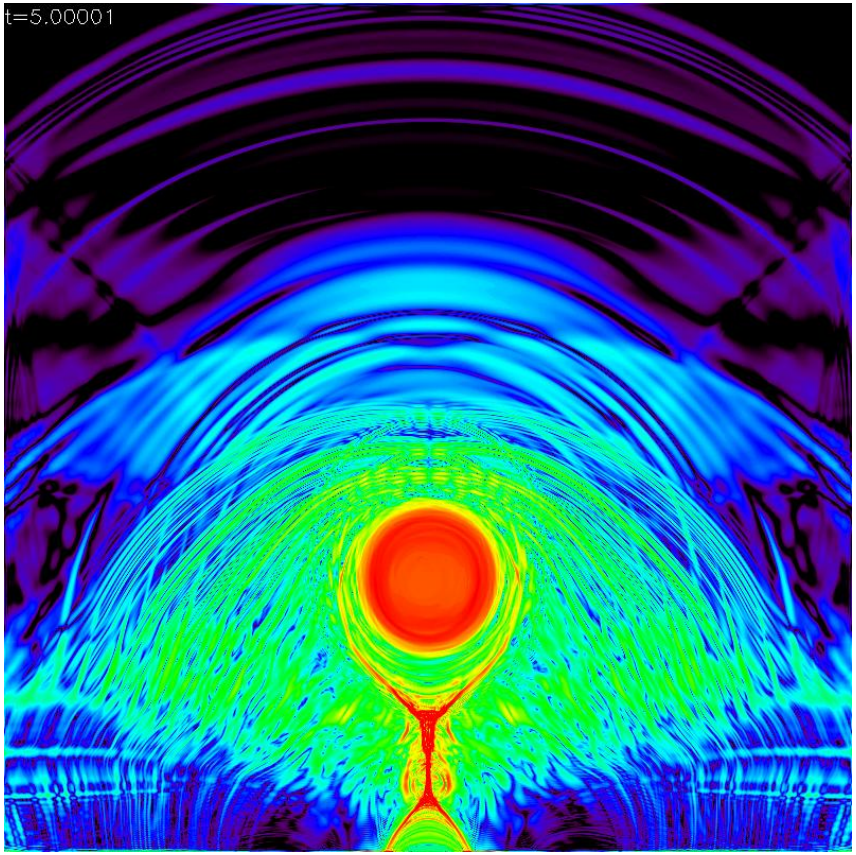


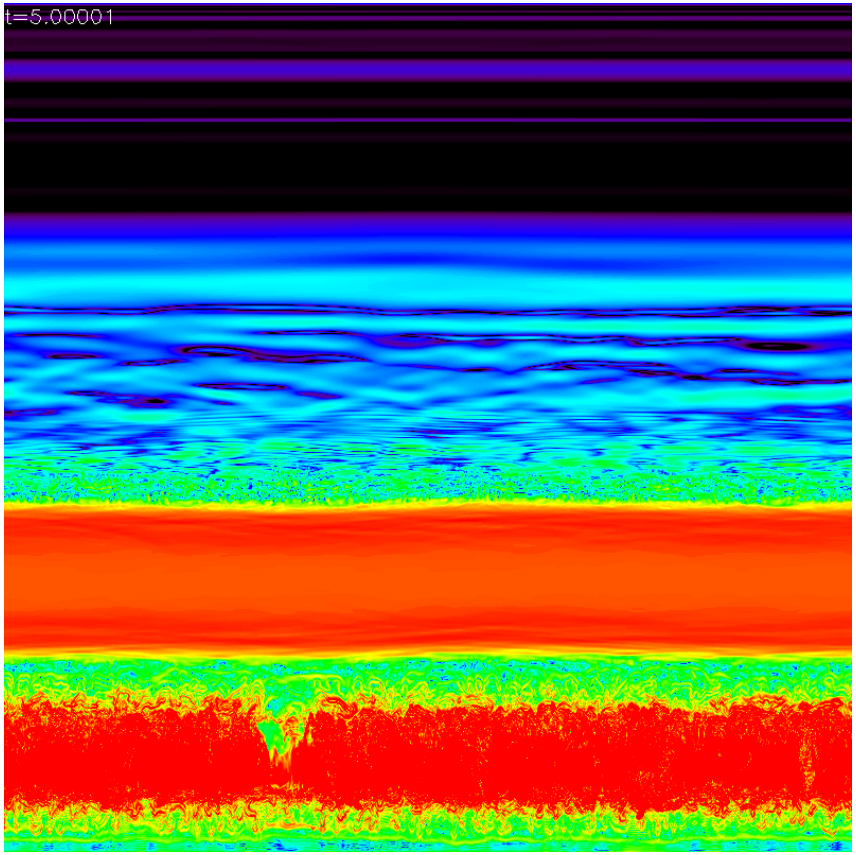


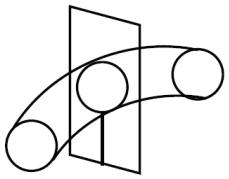


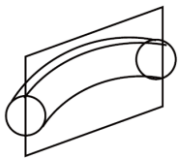


Electric current t=428 [sec]

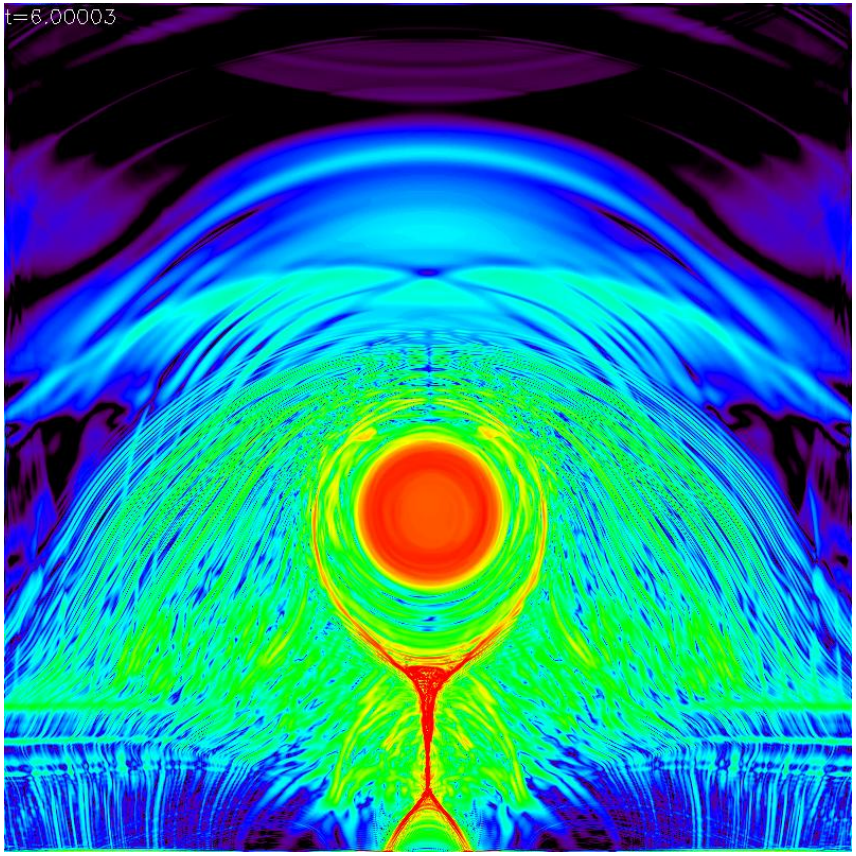


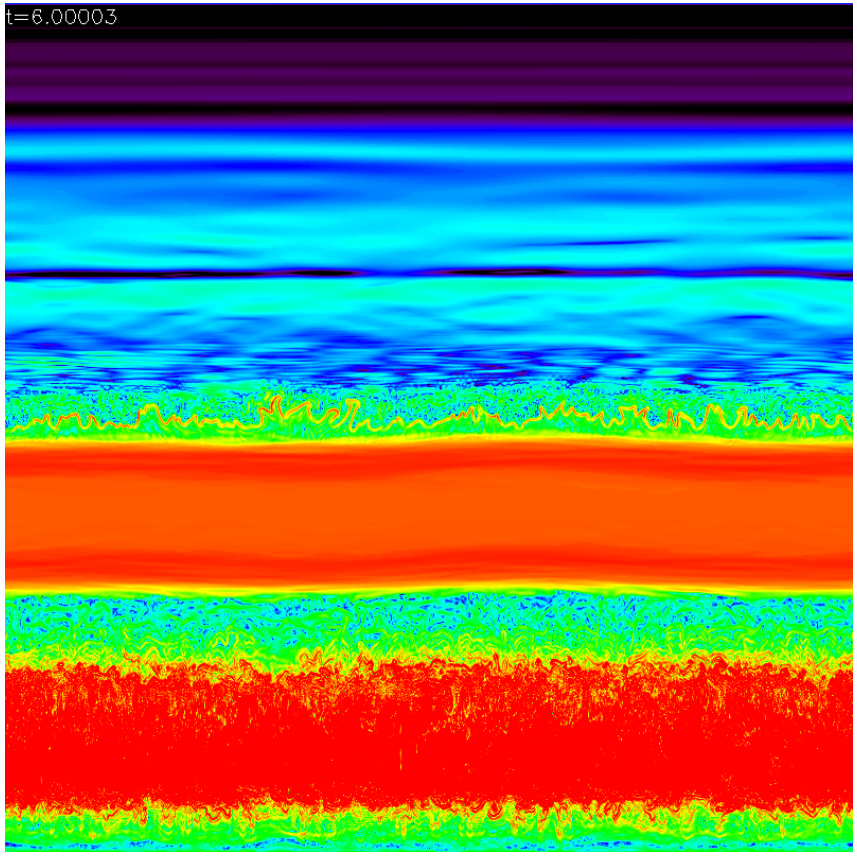


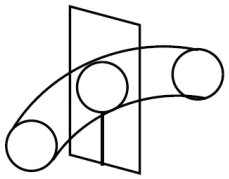


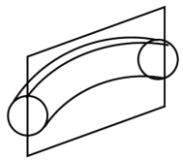


Electric current t=513 [sec]

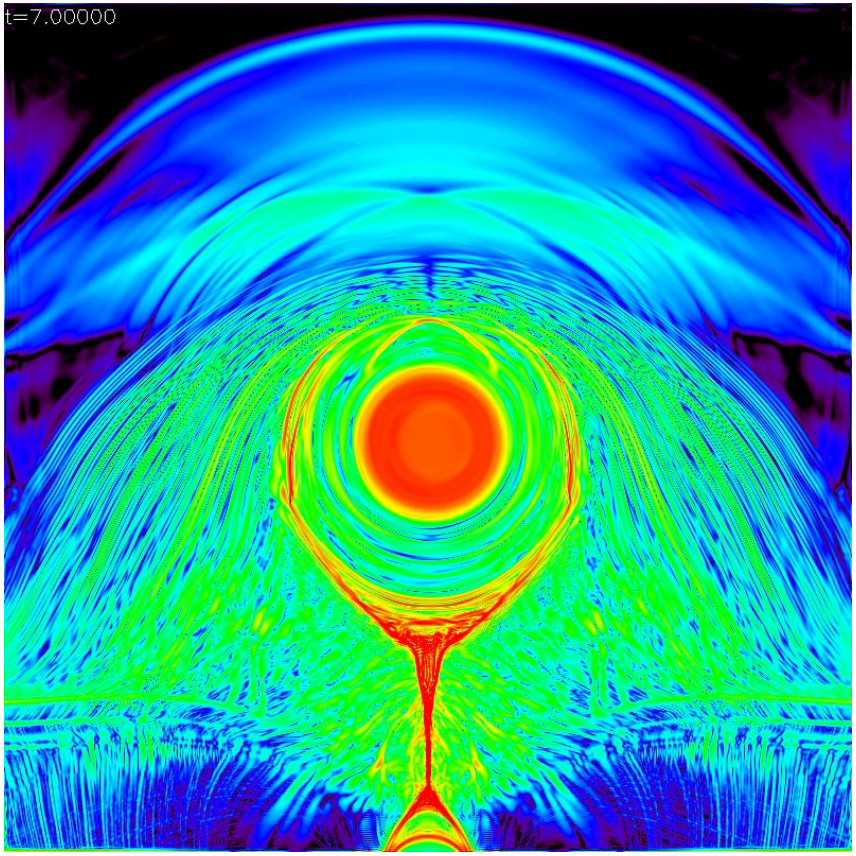


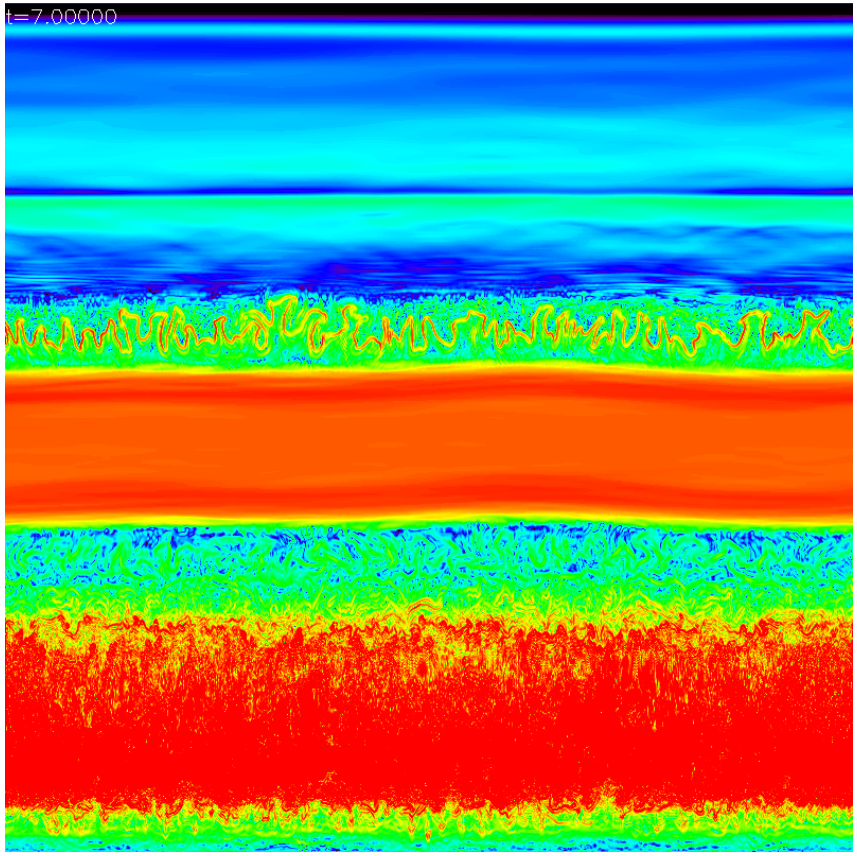


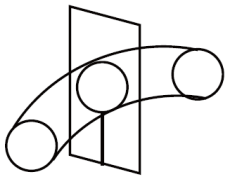


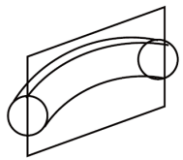


Electric current t=599 [sec]

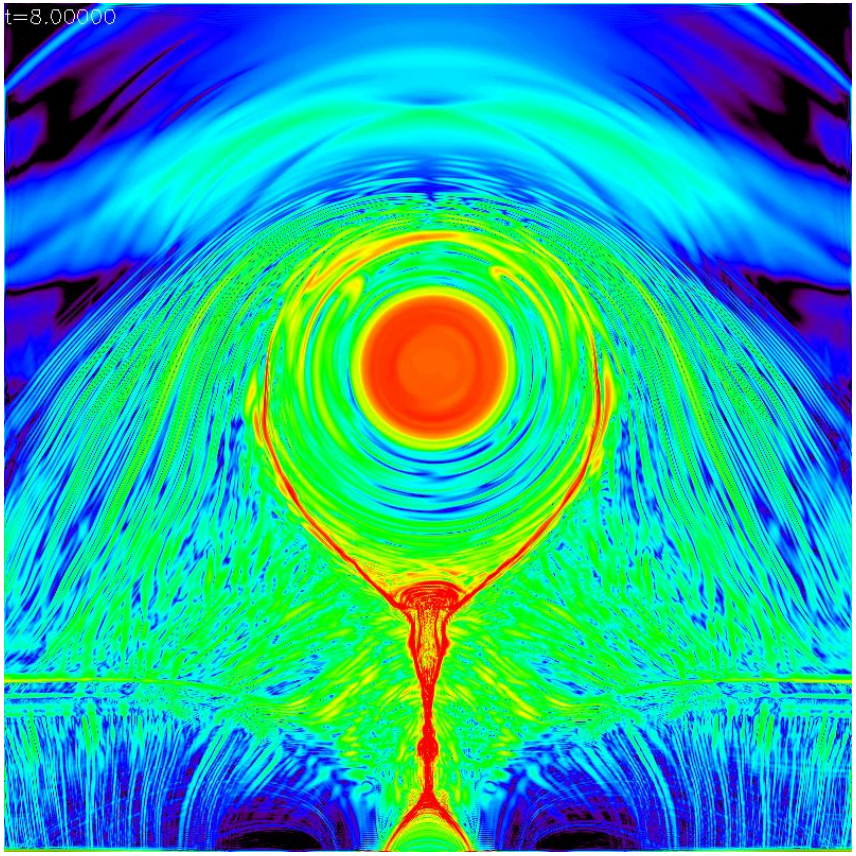


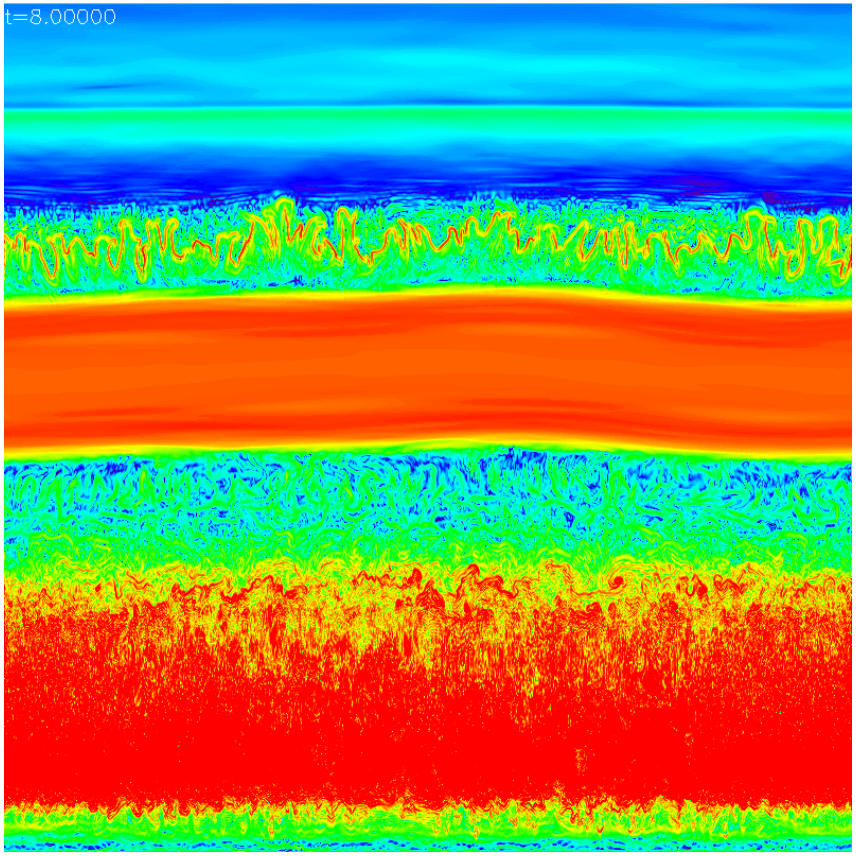


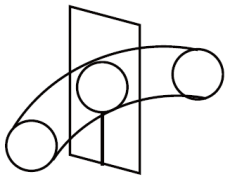


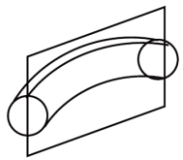


Electric current t=684 [sec]

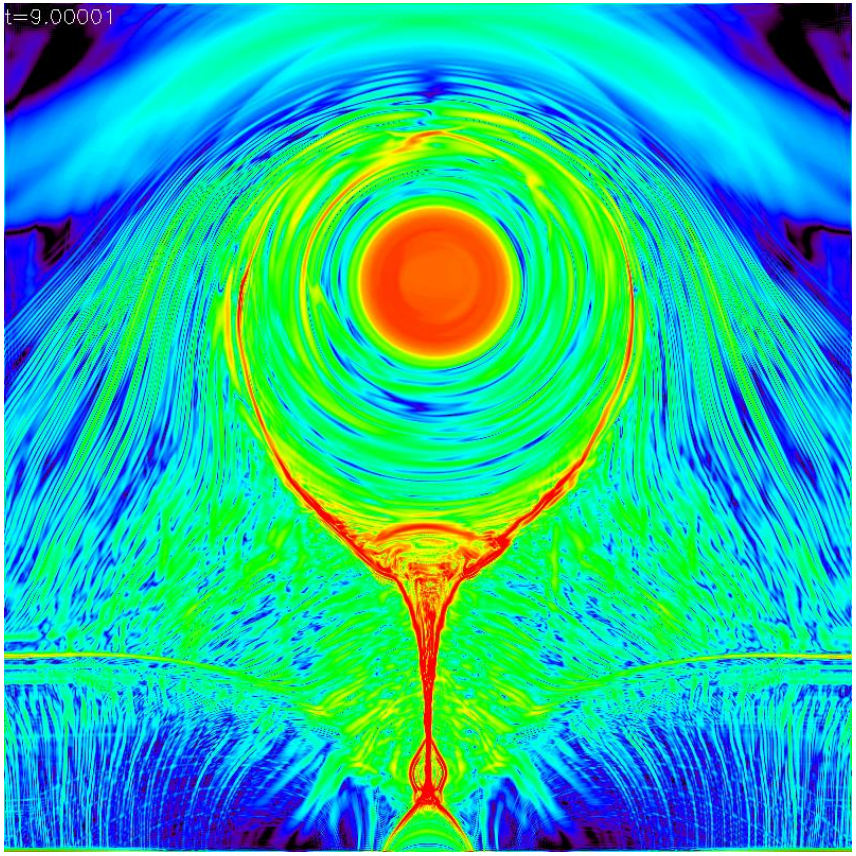


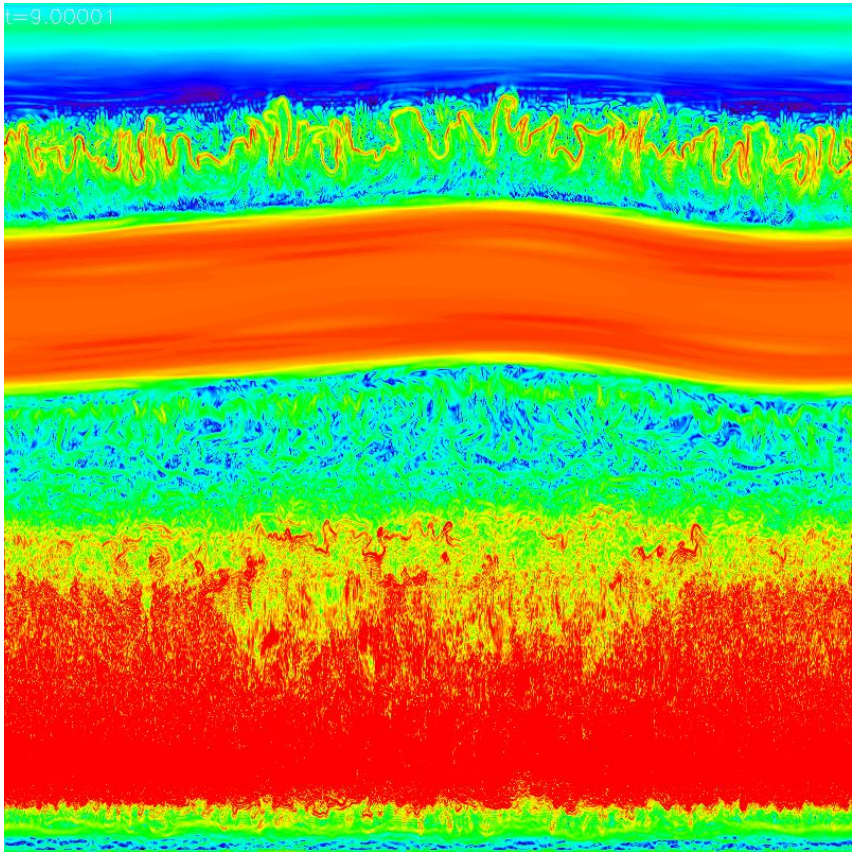


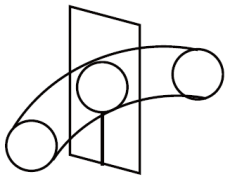


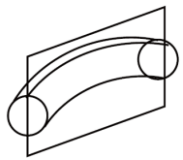


Electric current t=770 [sec]









Electric current t=855 [sec]