THE UNIVERSITY OF TOKYO

Energy partition of ions and electrons in the course of magnetic reconnection

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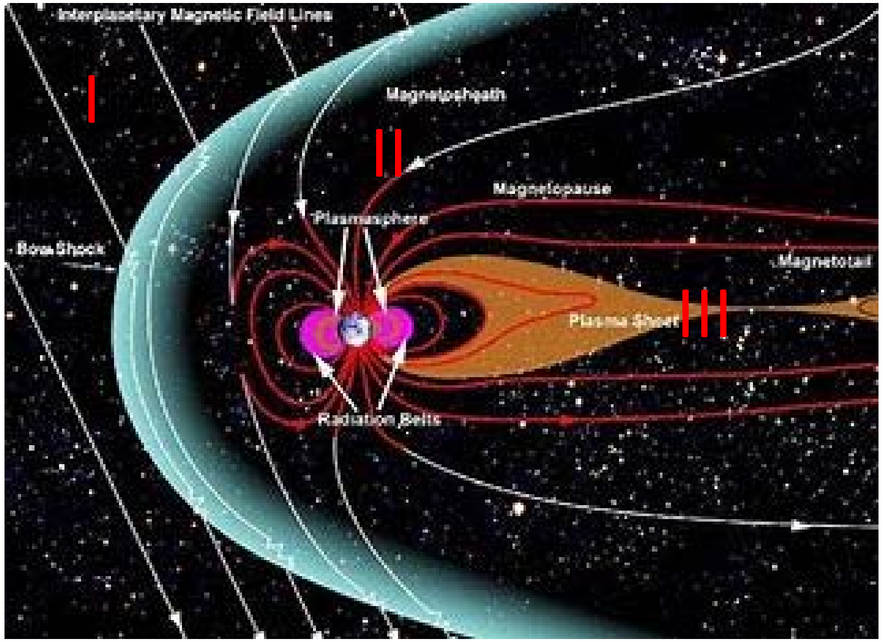
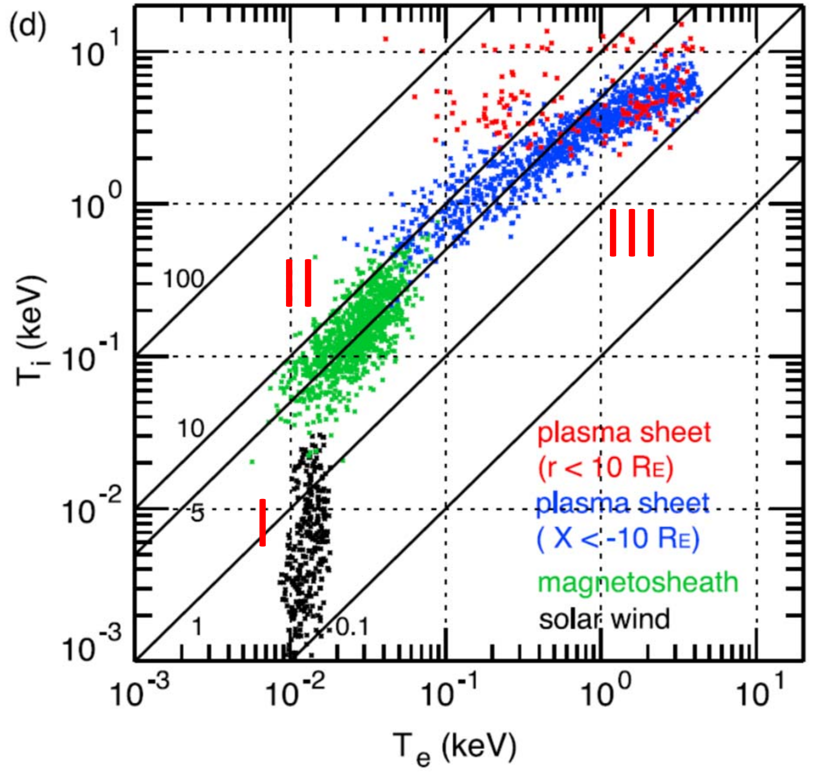
Observations of Ti/Te in Magnetosphere





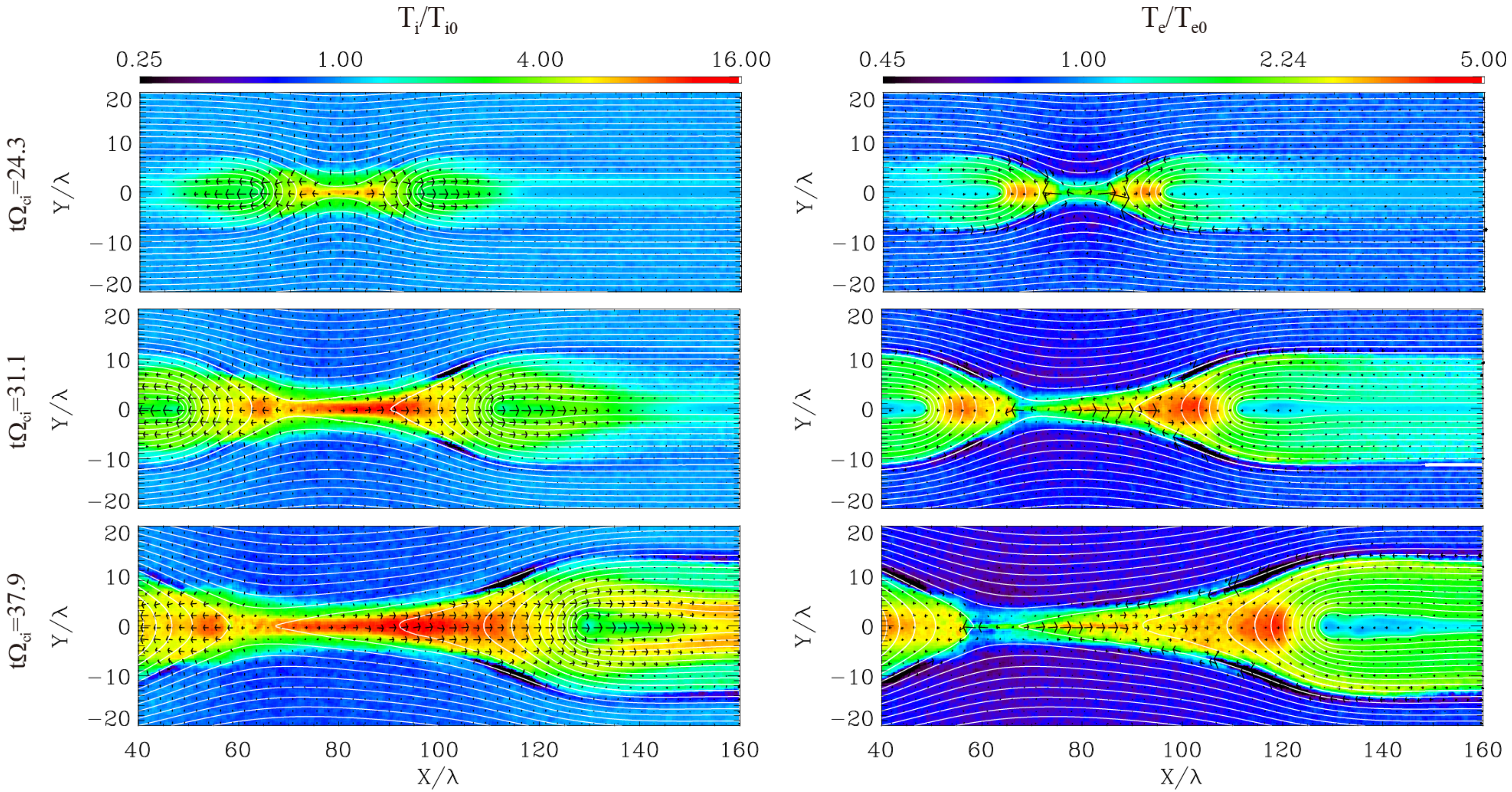
Hot ions in Earth's magnetotail are believed to be generated during magnetic reconnection

$$T_i/T_e = 5 \sim 10$$

(cf. Baumjohann+ JGR 1989; Eastwood+ PRL 2013; Phan+ GRL 2013)

Wang+ JGR 2012

T_i & T_e Heating in PIC simulation



cf. Simulation study of plasma heating: Wu+ PRL 2013; Shay+ PoP 2014; Haggerty+ GRL 2015

How can we understand the preferential ion heating?

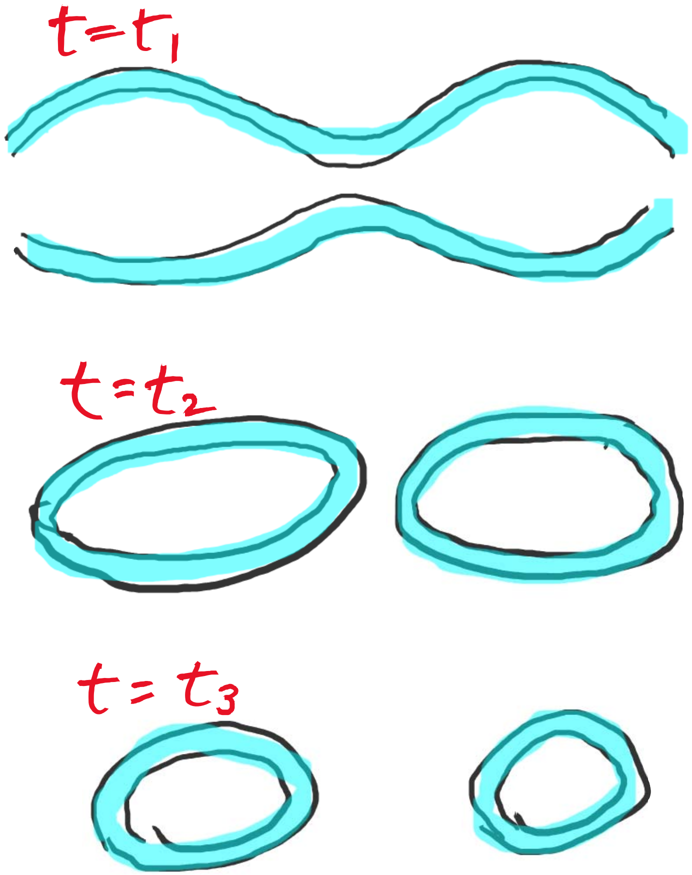
Distinguish adiabatic heating and non-adiabatic heating

$$\frac{D}{Dt}\left(\frac{p}{\gamma-1}\right)=\underbrace{\left(\frac{p}{\gamma-1}\right)\frac{\gamma}{\varrho}\frac{D\varrho}{Dt}}_{\text{Adiabatic}}+\underbrace{Q_{heat}}_{\text{Nonadiabatic}}$$

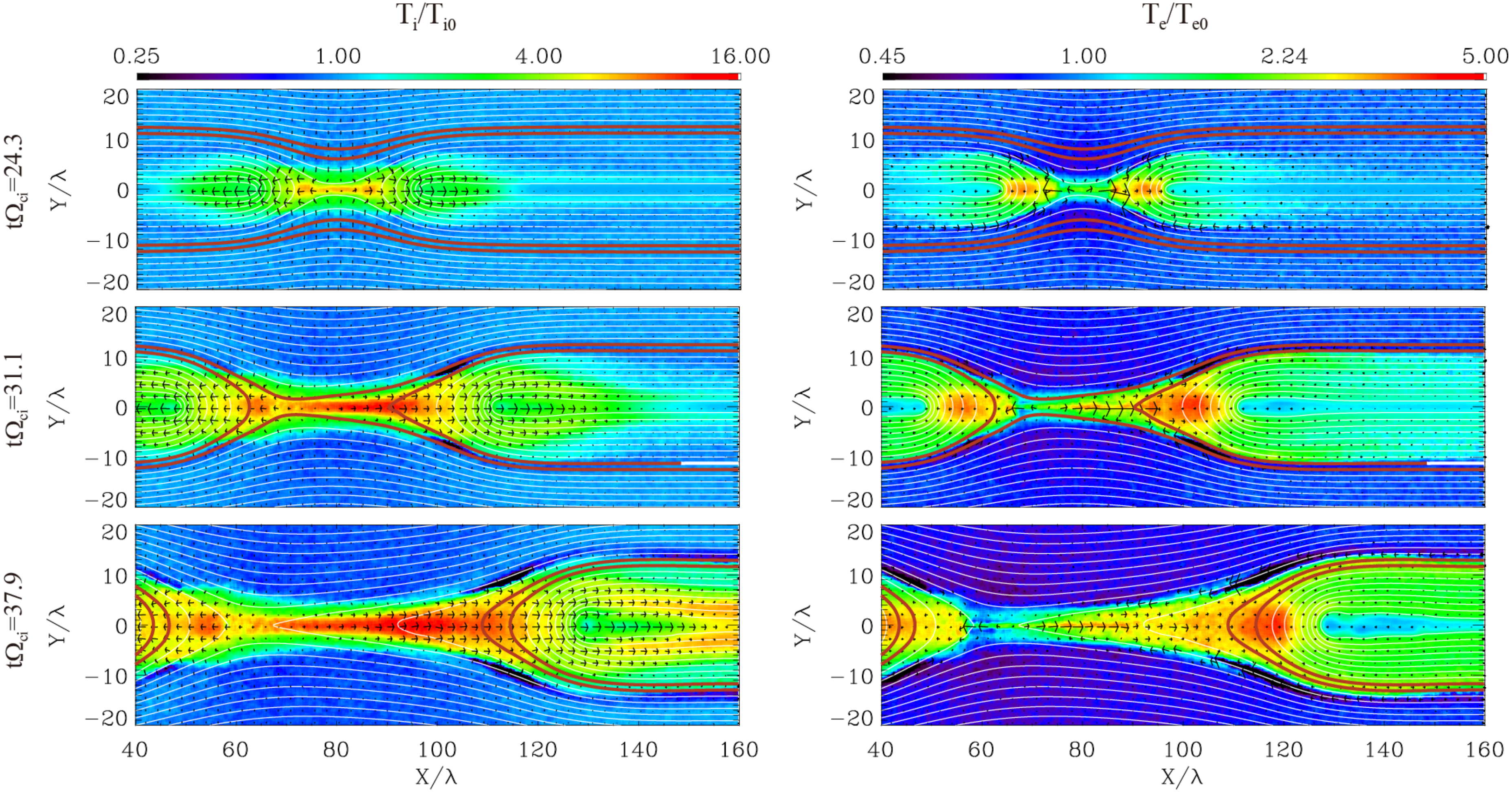
$$Q_{heat}=\underbrace{\eta J^2}_{\text{Ohmic/Joule Heating}}\quad+\quad\underbrace{\text{others}}_{\text{Slow Shock, Turbulence...}}$$

If adiabatic heating, $PV^{\gamma}=const$

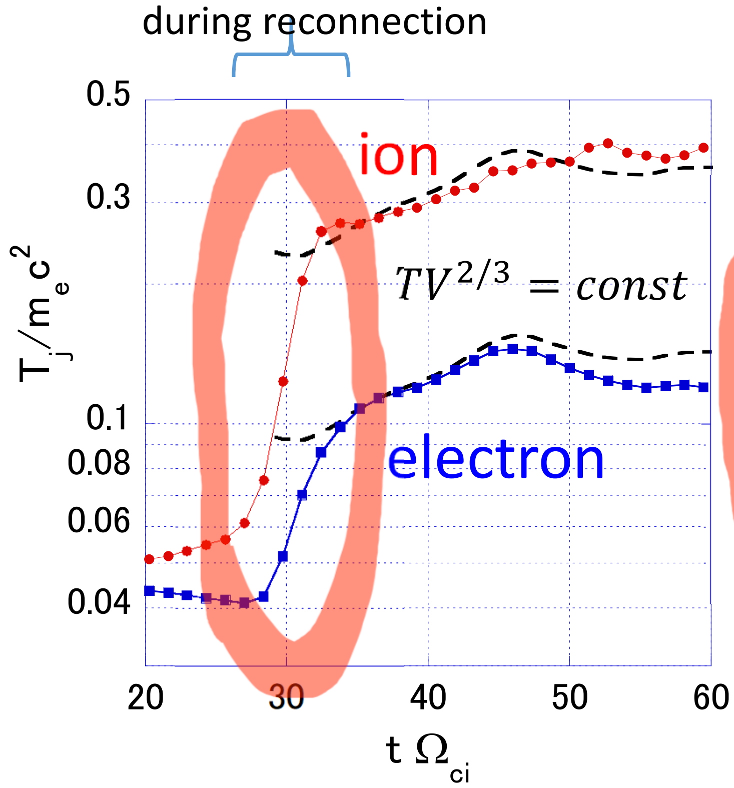
V is the volume of flux tube

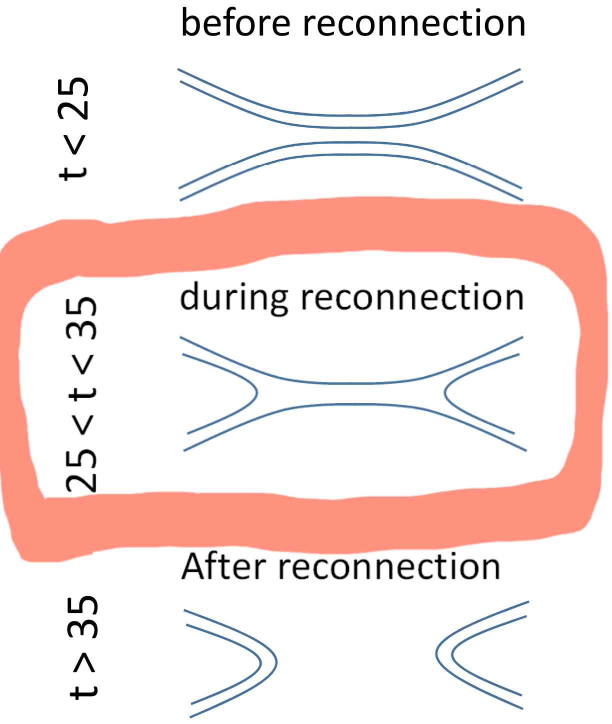


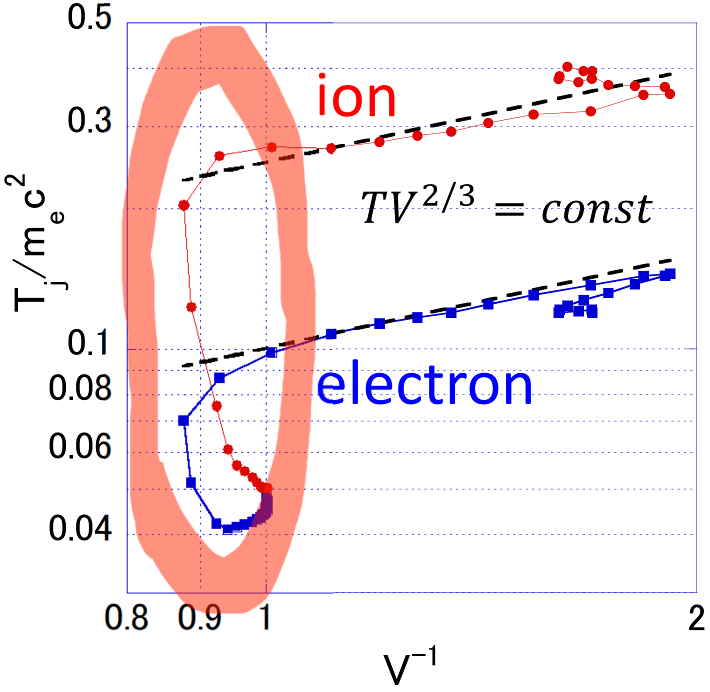
Evolution of Magnetic Flux Tube



Time History & T-V Relation



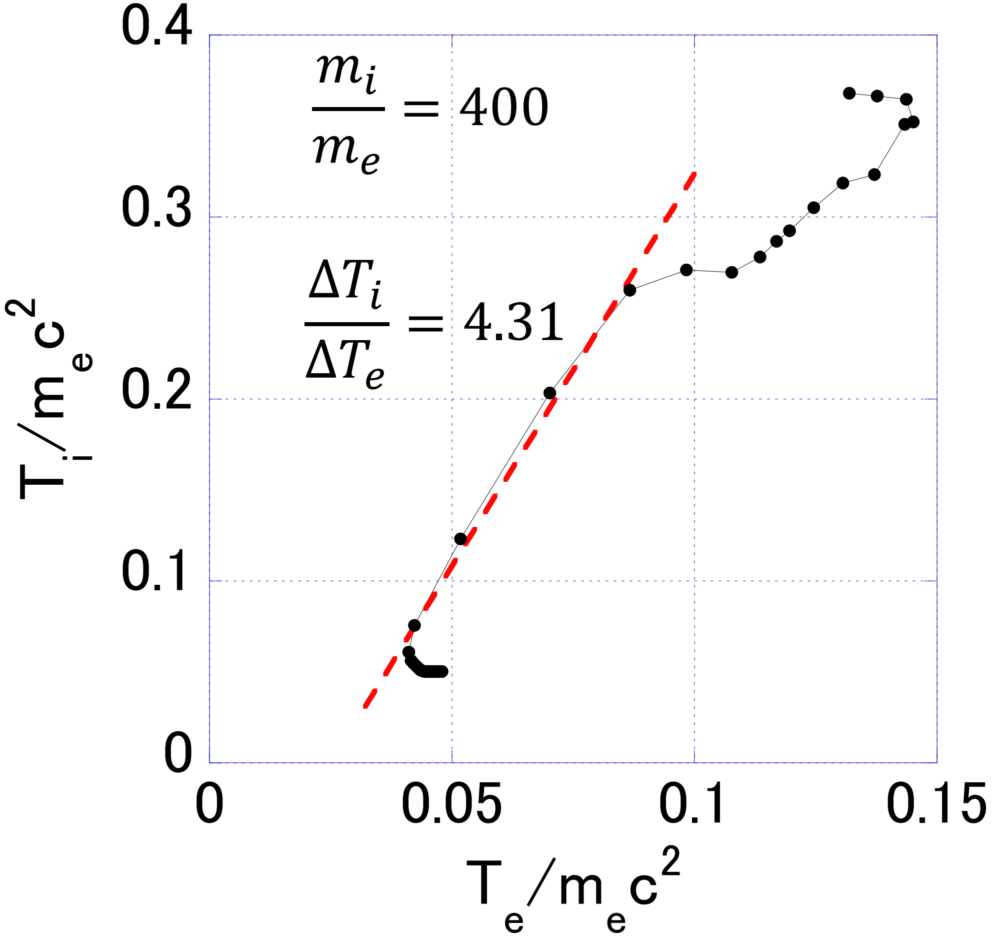


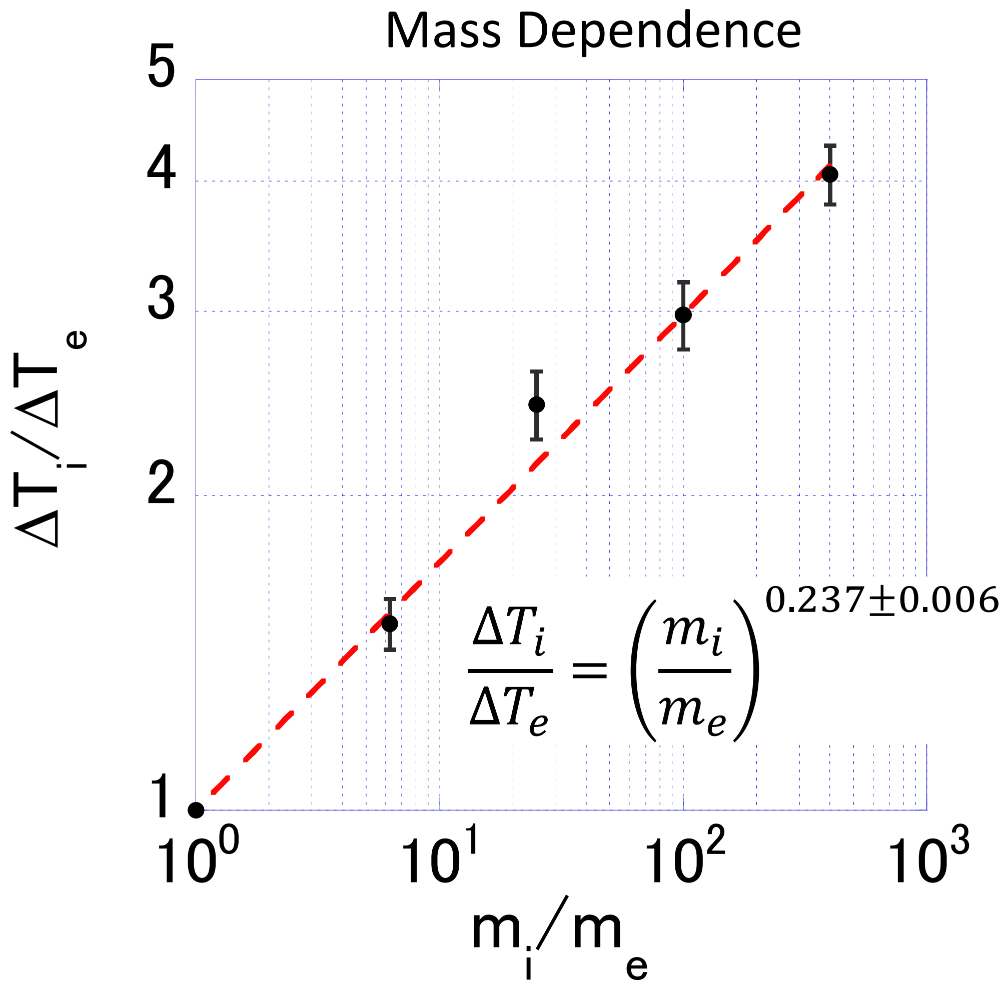


(V : Volume of Flux Tube)

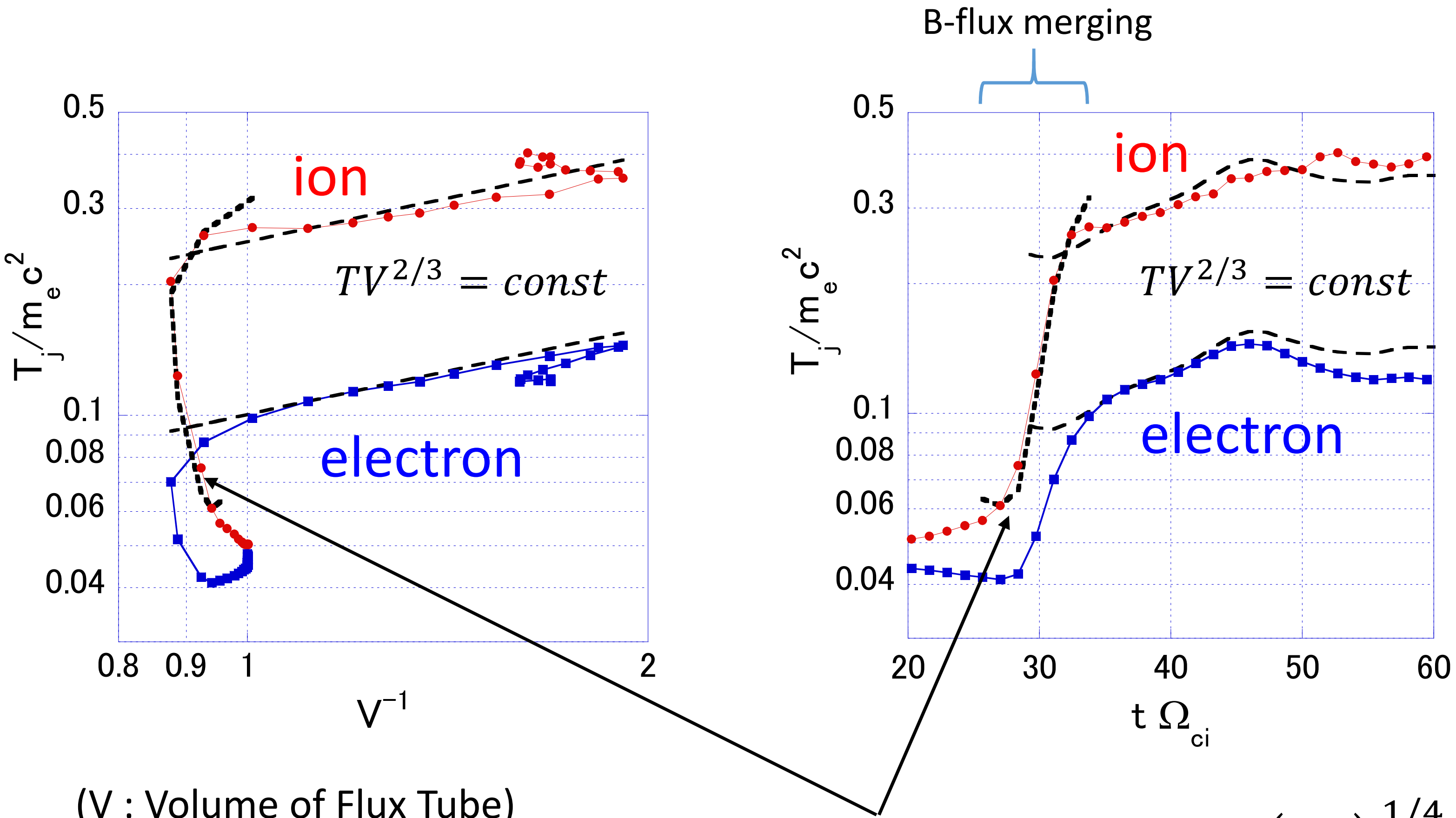
Adiabatic process after B-flux tube merging/re-connection

Ti/Te during B-flux merging stage





Thermodynamics of Reconnection

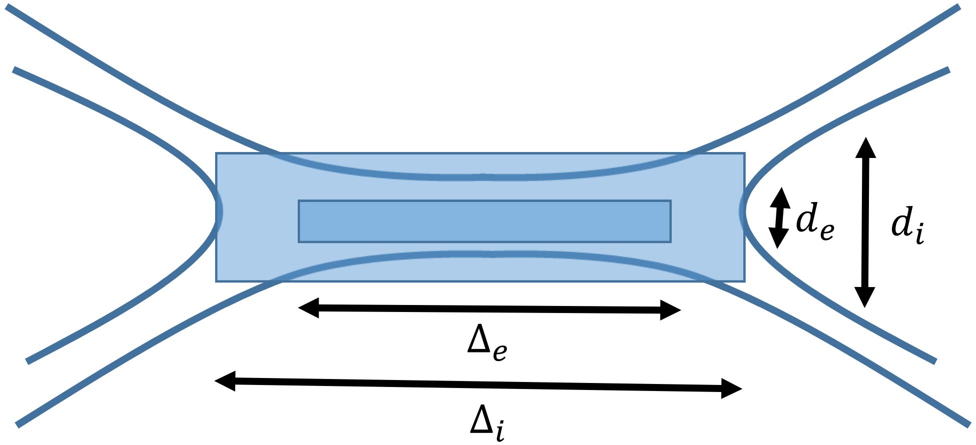


(V : Volume of Flux Tube)

Heating during
B-flux merging

$$\frac{\Delta T_i}{\Delta T_e} = \left(\frac{m_i}{m_e}\right)^{1/4}$$

Nonadiabatic heating during B-flux merging



collisionless/inertia conductivity

$$\sigma_j = \frac{ne^2}{m_j \nu_{c,j}} \propto \frac{\Delta_j}{\left(m_j T_j\right)^{1/2}}$$

(e.g. Coppi+ 1966; Hoh 1966; Galeev & Zeleny 1976)

meandering length

$$d_j = \sqrt{\frac{v_{th,j}\lambda}{\Omega_{cj}}} \propto \left(m_j T_j\right)^{1/4}$$

(e.g., Sonnerup 1971)

width of reconnection region

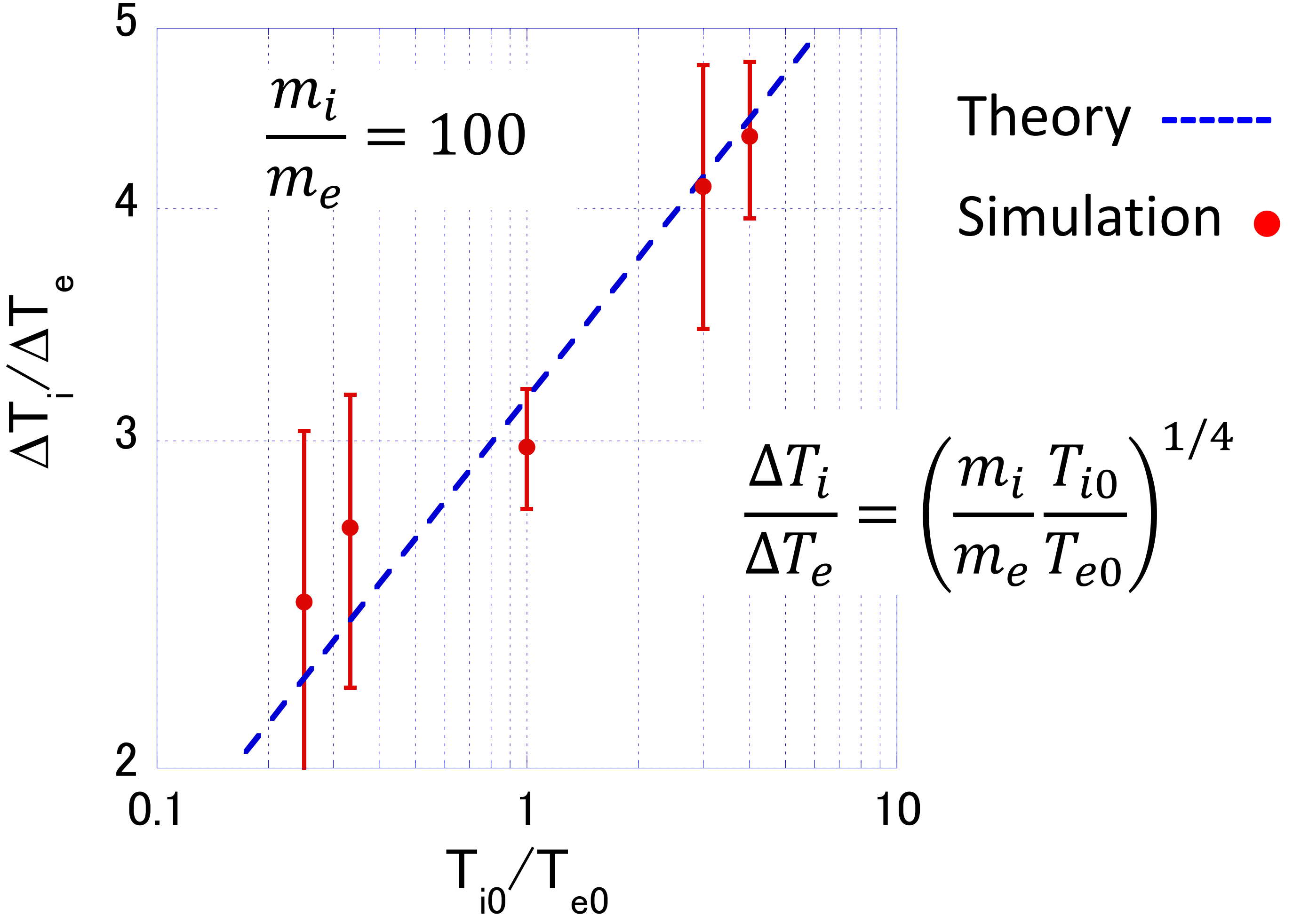
$$\Delta_j \propto \left(m_j T_j\right)^{1/4}$$

(e.g., Coroniti 1985)

$$\frac{\Delta T_i}{\Delta T_e} = \frac{ion\ Joule\ heating}{ele.\ Joule\ heating} = \frac{\sigma_i E^2 \Delta_i d_i}{\sigma_e E^2 \Delta_e d_e}$$

$$\frac{\Delta T_i}{\Delta T_e} = \frac{(m_i T_i)^{1/4}}{(m_e T_e)^{1/4}}$$

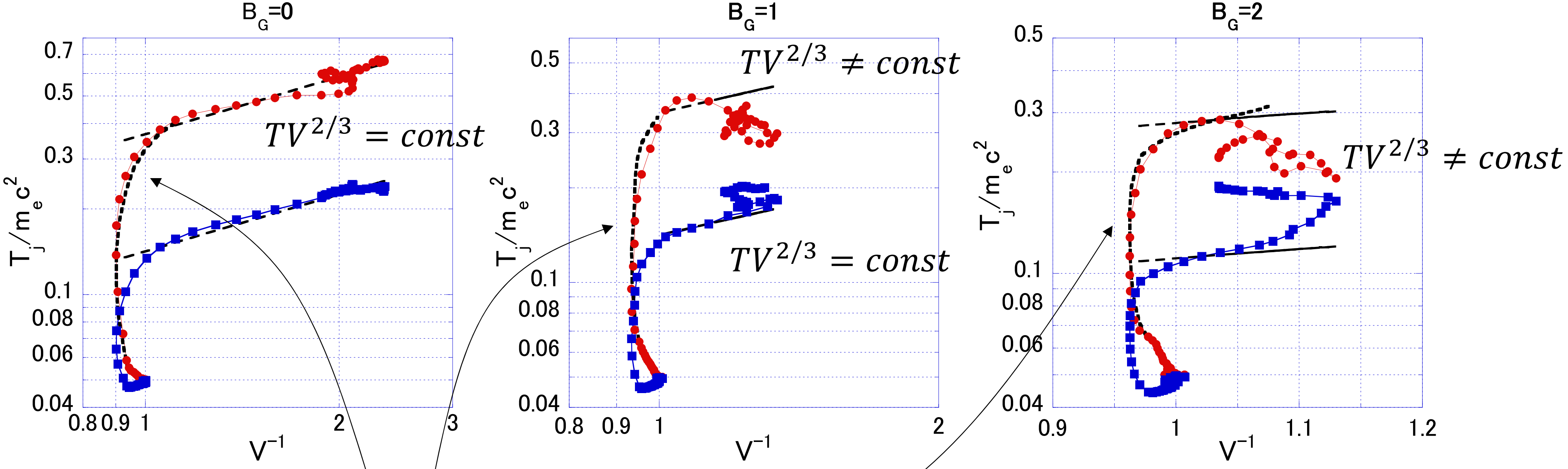
initial temperature dependence



$$\frac{\Delta T_i}{\Delta T_e} = \left(\frac{m_i}{m_e}\frac{T_{i0}}{T_{e0}}\right)^{1/4}$$

Guide Magnetic Field Effect

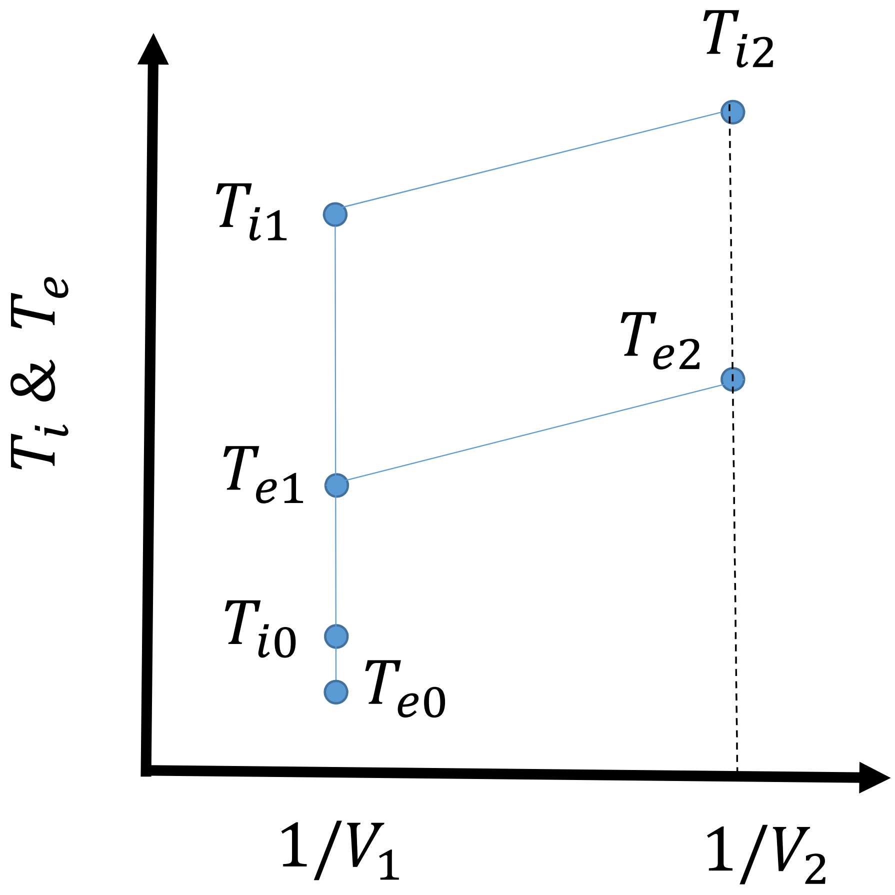
$$\frac{m_i}{m_e} = 100$$



$$\frac{\Delta T_i}{\Delta T_e} = \left(\frac{m_i}{m_e}\right)^{1/4}$$

weak compressibility

Thermodynamics of Reconnection



$$\frac{T_{i1} - T_{i0}}{T_{e1} - T_{e0}} = \left(\frac{m_i}{m_e}\frac{T_{i0}}{T_{e0}}\right)^{1/4}$$

$$\frac{T_{e2}}{T_{e1}} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \quad \gamma = \frac{5}{3}$$

$$\frac{T_{i2}}{T_{i1}} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

Summary

- Energy Partition of Ion & Electron during Magnetic Reconnection
- Two distinct heating stages:
  - Effective Ohmic/Joule Heating

$$\frac{\Delta T_i}{\Delta T_e} = \left(\frac{m_i}{m_e}\frac{T_{i0}}{T_{e0}}\right)^{1/4}$$

  - Adiabatic Compression (for anti-parallel reconnection)

$$\frac{D}{Dt}(TV^{\gamma-1}) = 0$$

- Ion heating is less effective with increasing B_G field