Self-organization of Reconnecting Plasmas to a Marginally Collisionless State

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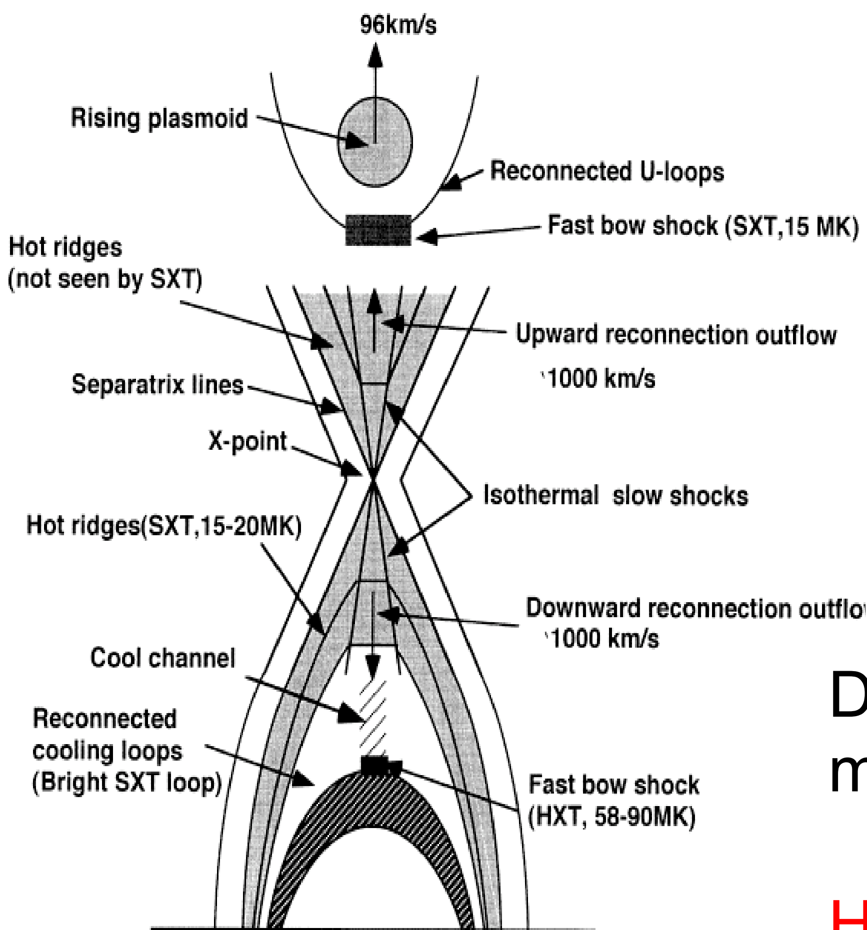
Introduction 1

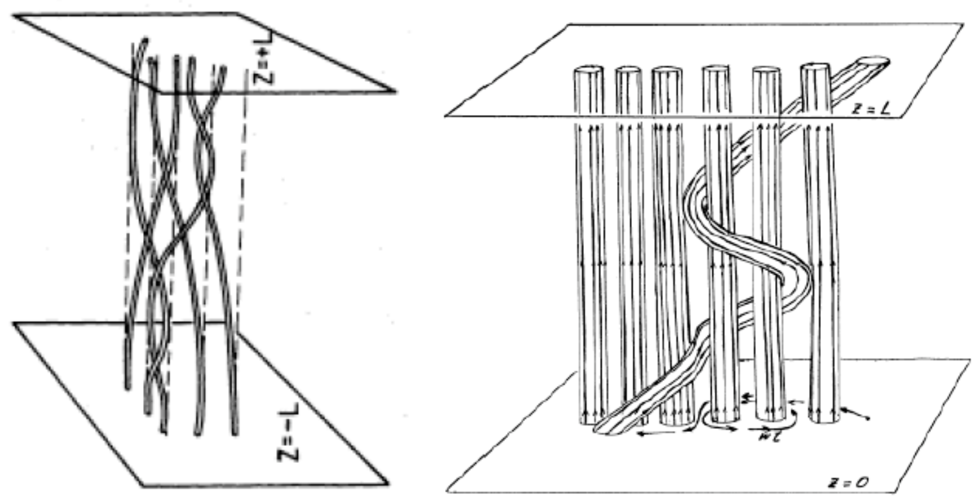
The role of Magnetic reconnection

Solar Flare



Tsuneta +, 1996

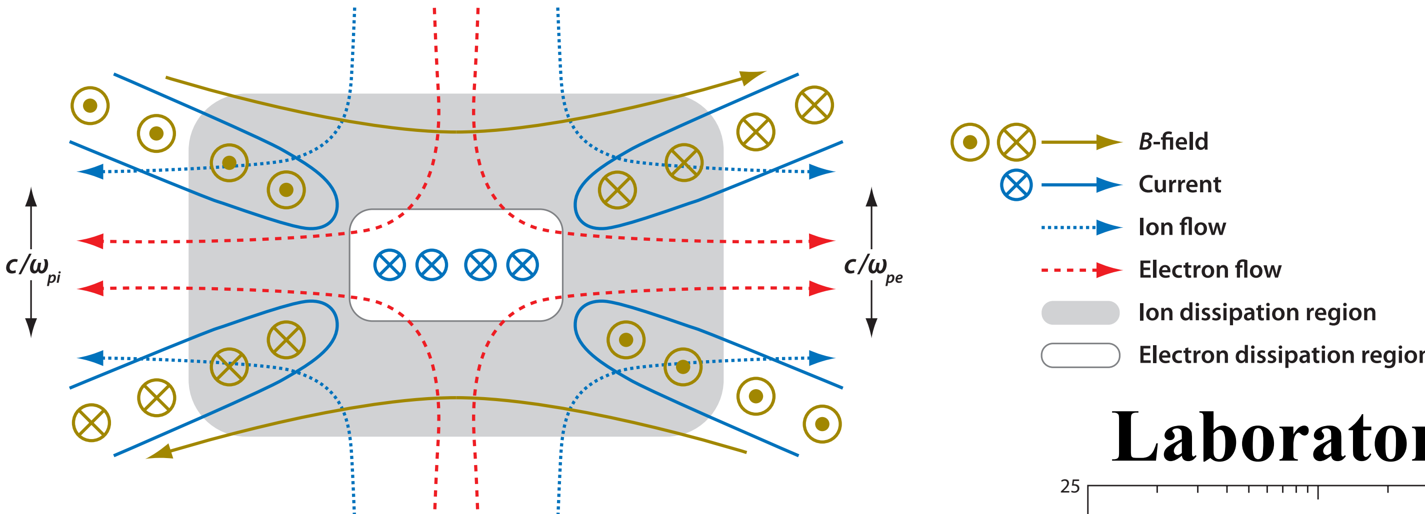
Coronal heating, micro/nano-flare



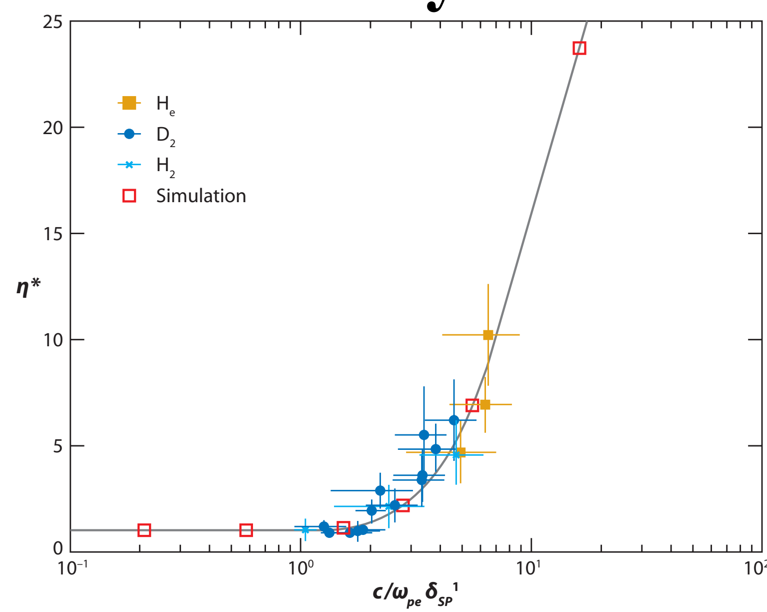
Dynamical corona is made by magnetic reconnection.

However, when fast RX occurs is still not clear.

Introduction 2
Collisionless Reconnection



Laboratory Plasma



Current sheet thickness

< ion inertia length

Collisionless (Hall) RX

→ Fast RX

Relationship large & small scale?

Yamada +, 2006

Introduction 3
Solar Corona and Earth's Magnetosphere

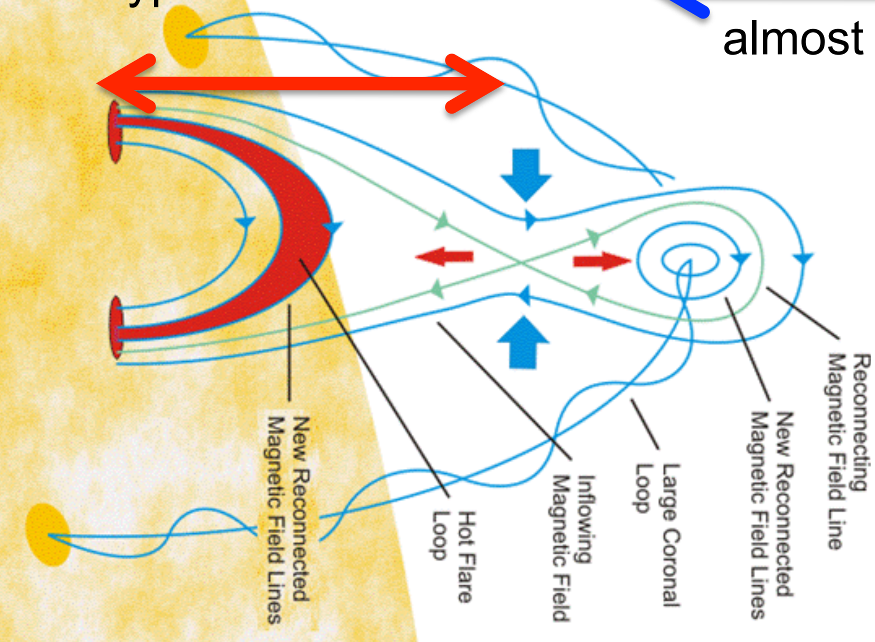
Solar corona (flare)

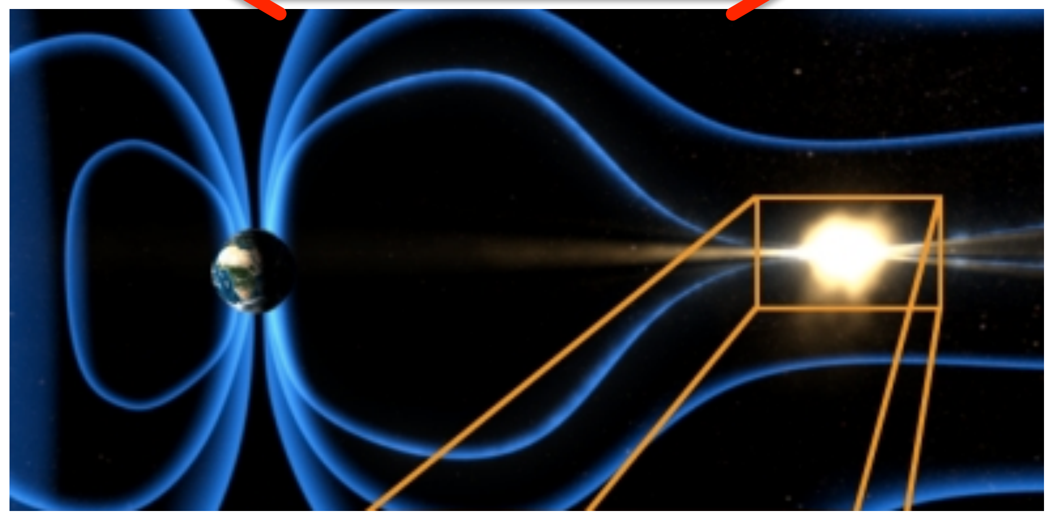
Typical scale = 10^5 km

almost same

Earth's magnetosphere (substorm)

Typical scale = 10^5 km



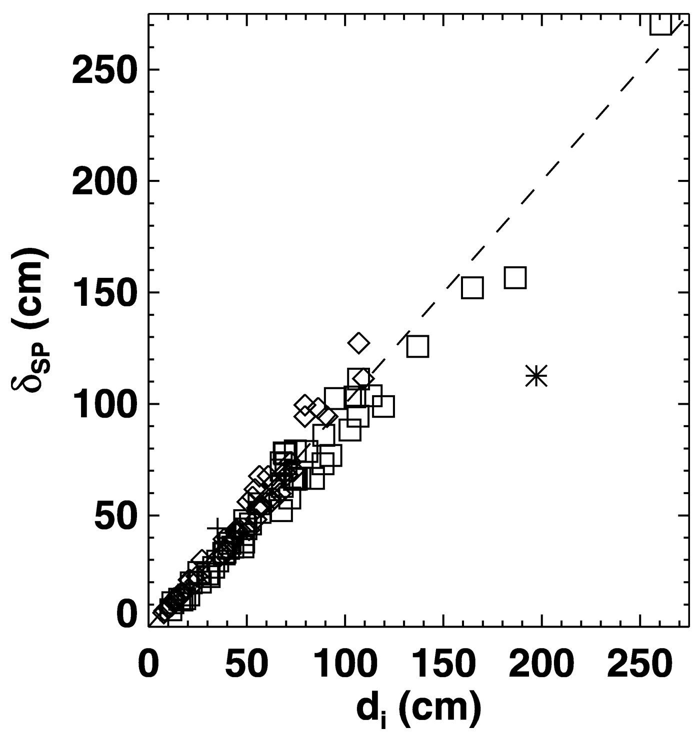


Macro-scale	→	Sun : 10^5 km	Earth : 10^5 km	same
Micro-scale	→	Sun : 10^{-3}km	Earth : 10^3 km	6 order
Macro/Micro	→	Sun : 10^8	Earth : 10^2	6 order

→ Macro/Micro is largely different!

Marginally Collisionless Plasma

Uzdensky 2007 proposed a self-regulating process keeping the plasma marginally collisionless in solar corona.



Cassak+ 2008 also discussed self-regulating process and found the observational implication from 107 flares (Sun-like star).

Today's Talk

Basically, we discuss coronal heating problem along nano-flare heating model.

Method: 1D Hydrodynamic calculation which is popular in the category of solar physics

New points: Include the regime transition from collisional to collisionless reconnection.

Aim: To understand what's happened in a large scale coronal loop with the transition and its feed back.

Main difference from past studies: The plasma actively decides its heating rate.

1D Hydrodynamic Calculation

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho V_x) = 0,$$

CANS 1D HD

Modified Lax- *Wendroff*

gravity

$$\frac{\partial}{\partial t}(\rho V_x) + \frac{\partial}{\partial x}(\rho V_x^2 + p) = -\rho g_{\|},$$

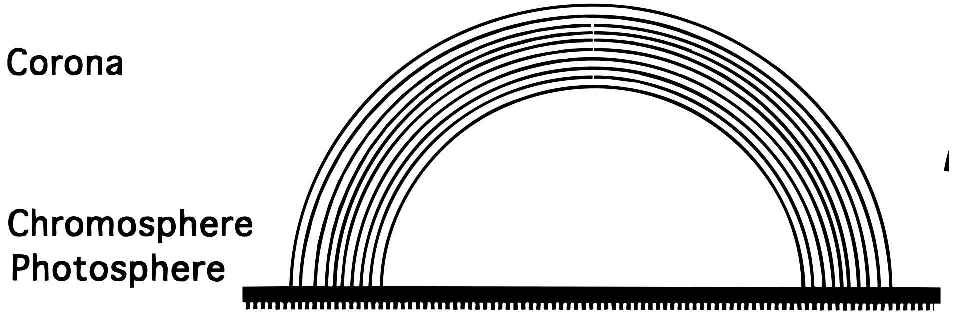
Thermal conduction

$$\frac{\partial}{\partial t}\left(\frac{p}{\gamma - 1} + \frac{1}{2}\rho V_x^2\right) + \frac{\partial}{\partial x}\left[\left(\frac{\gamma}{\gamma - 1}p + \frac{1}{2}\rho V_x^2\right)V_x - \kappa_{\|}\frac{\partial T}{\partial x}\right]$$

$$= -\rho g_{\|} V_x + H - R,$$

Radiative cooling

Half loop length 26 Mm



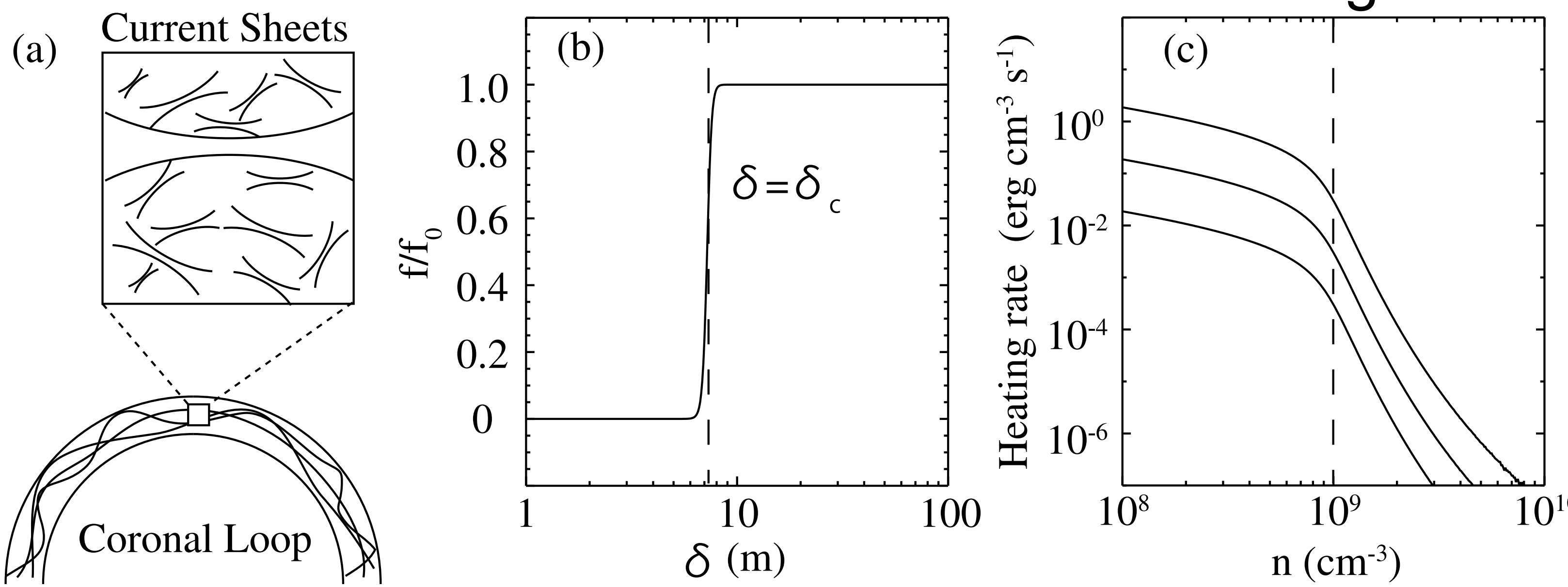
Heating
e.g., micro/nano-flare

New point：Heating term by RX

＊＊＊Assumption＊＊＊

If current sheet thickness is less than ion inertia length, fast collisionless reconnection occurs.

CS thickness　　Heating rate



Time independent (not good assumption)

$$f(\delta) = \frac{1}{2} f_0 \left(\tanh\left(\frac{\delta - \delta_c}{\lambda} \right) + 1 \right),$$

$$H_1(\delta_i) = \dot{E} \int_0^{\delta_i} f d\delta = H_{c1} \left(\frac{\delta_i}{\delta_c} + \frac{\lambda}{\delta_c} \log \left(\frac{\cosh\left(\frac{\delta_i - \delta_c}{\lambda}\right)}{\cosh\left(\frac{\delta_c}{\lambda}\right)} \right) \right),$$

Other heating functions

$$H(n,T) = H_1(n) + H_2(n,T) + H_3(n,T)$$

Collisionless RX

$$H_1(\delta_i) = \dot{E}\int_0^{\delta_i} f\, d\delta = H_{c1}\left(\frac{\delta_i}{\delta_c} + \frac{\lambda}{\delta_c}\log\left(\frac{\cosh\left(\frac{\delta_i-\delta_c}{\lambda}\right)}{\cosh\left(\frac{\delta_c}{\lambda}\right)}\right)\right)$$

Collisional heating (*Sweet-Parker RX*)

$$H_2(T) = H_{c2} \times \left(\frac{T}{T_c}\right)^{-\frac{3}{4}} \left(\frac{\rho}{\rho_c}\right)^{-\frac{1}{4}}$$

Unknown heating to produce robust chromosphere

$$H_3(\rho,T) = \frac{H_{c3}}{2}\frac{\rho}{\rho_0}\left(\frac{T}{T_0}\right)^{-\frac{3}{4}}\left(1+\tanh\left(\left(\frac{\rho}{\rho_{cl}}-1\right)/\lambda_3\right)\right)$$

New point : Heating term by RX

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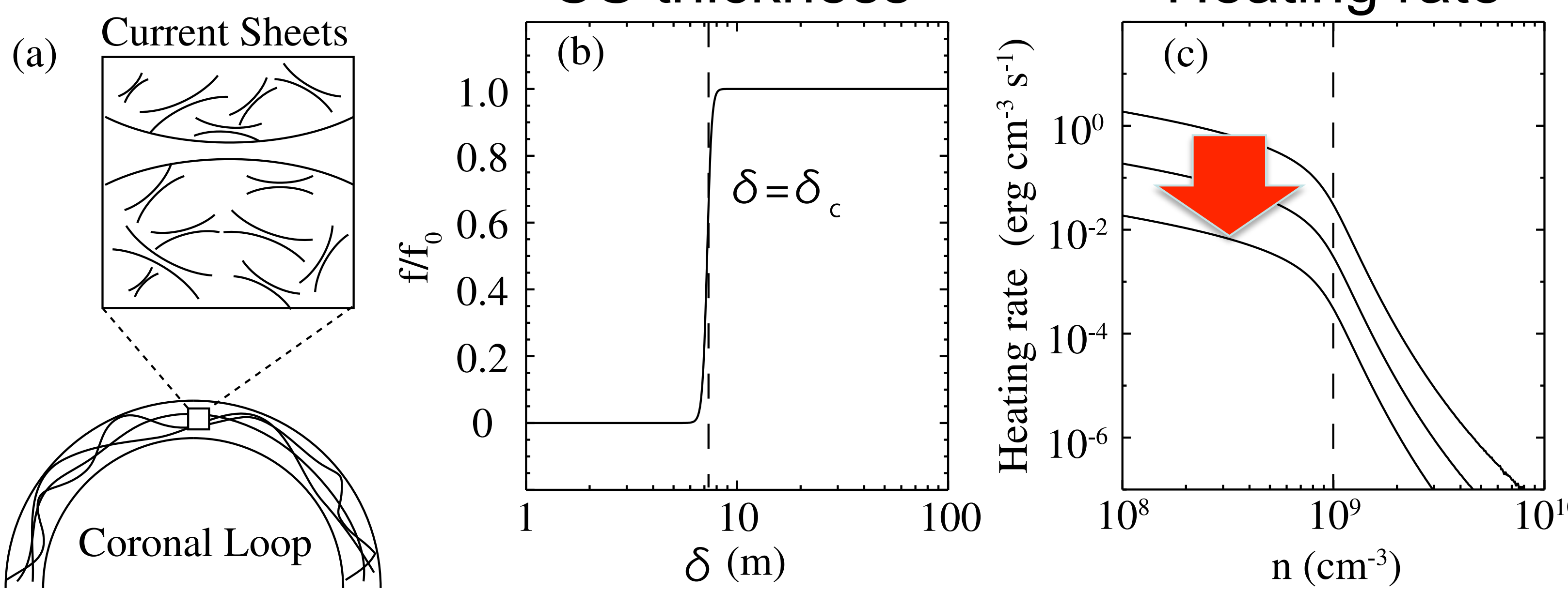
CS thickness

Heating rate



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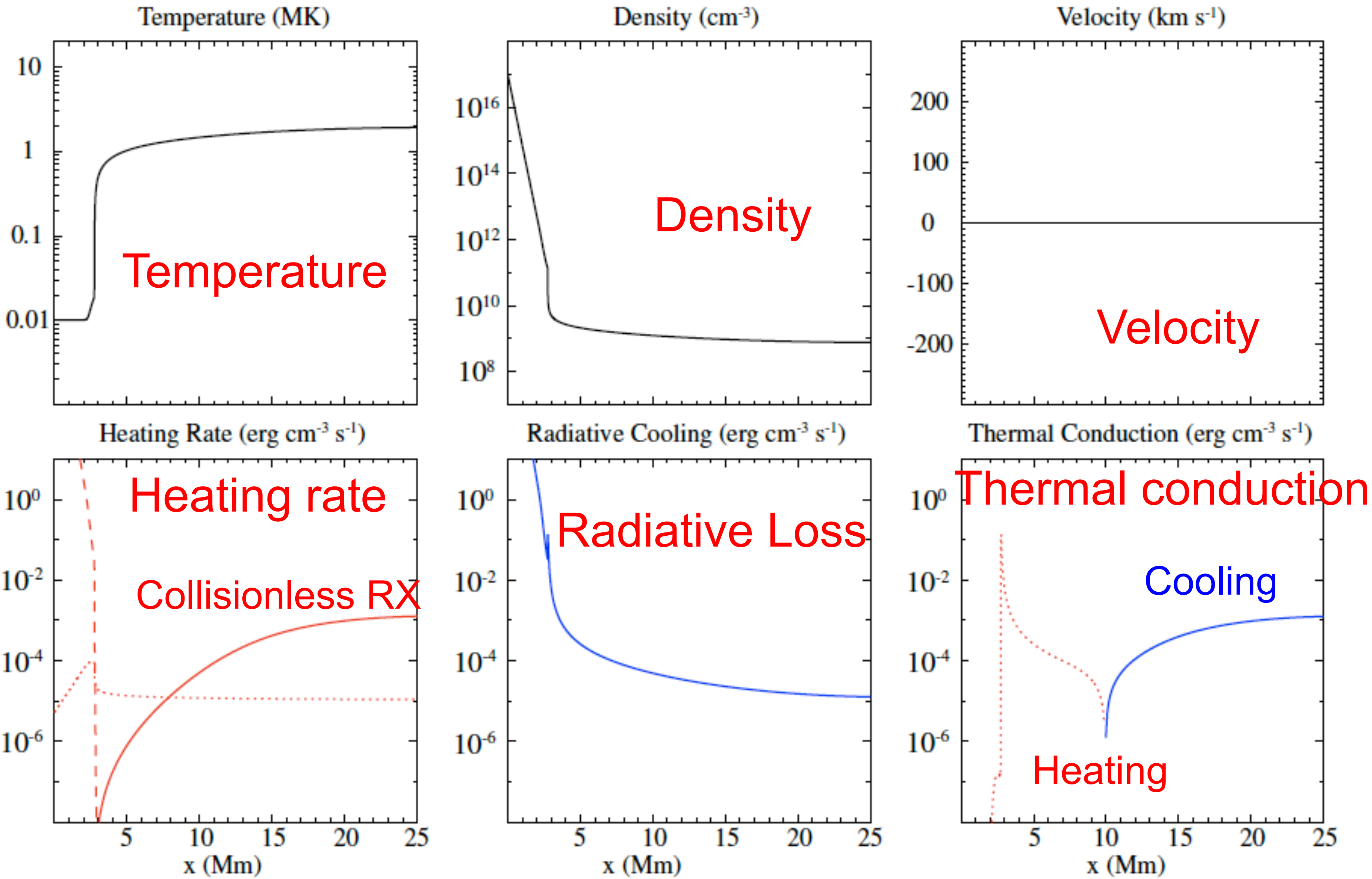
Weak heating: Usual corona



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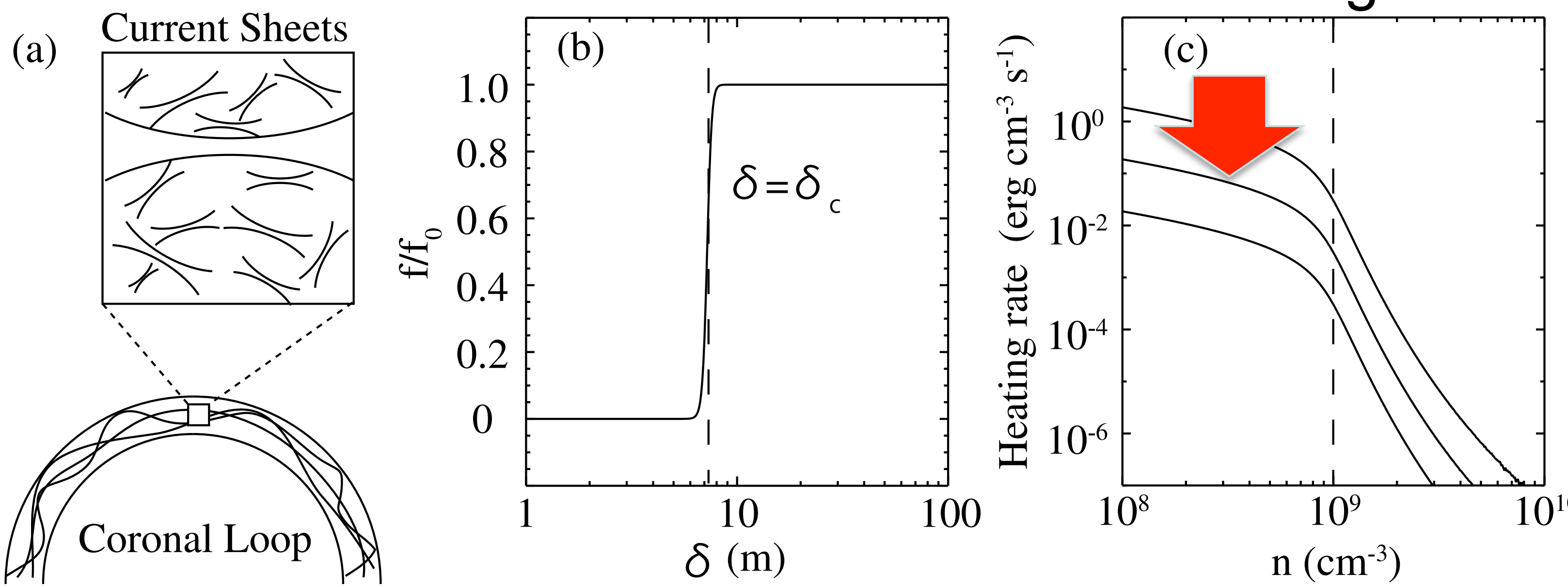

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Middle heating: Micro/nano-flaring

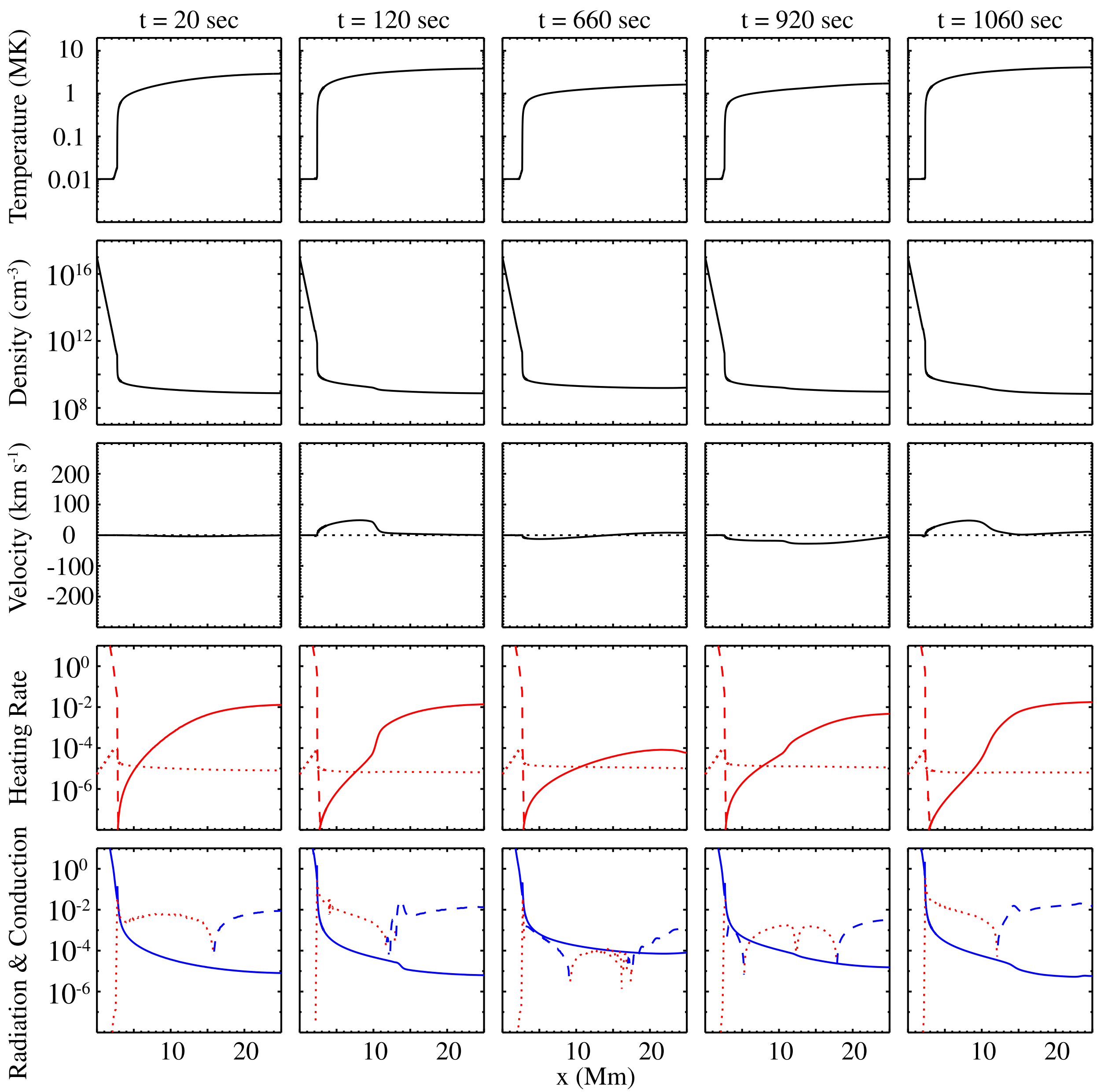
Temperature

Density

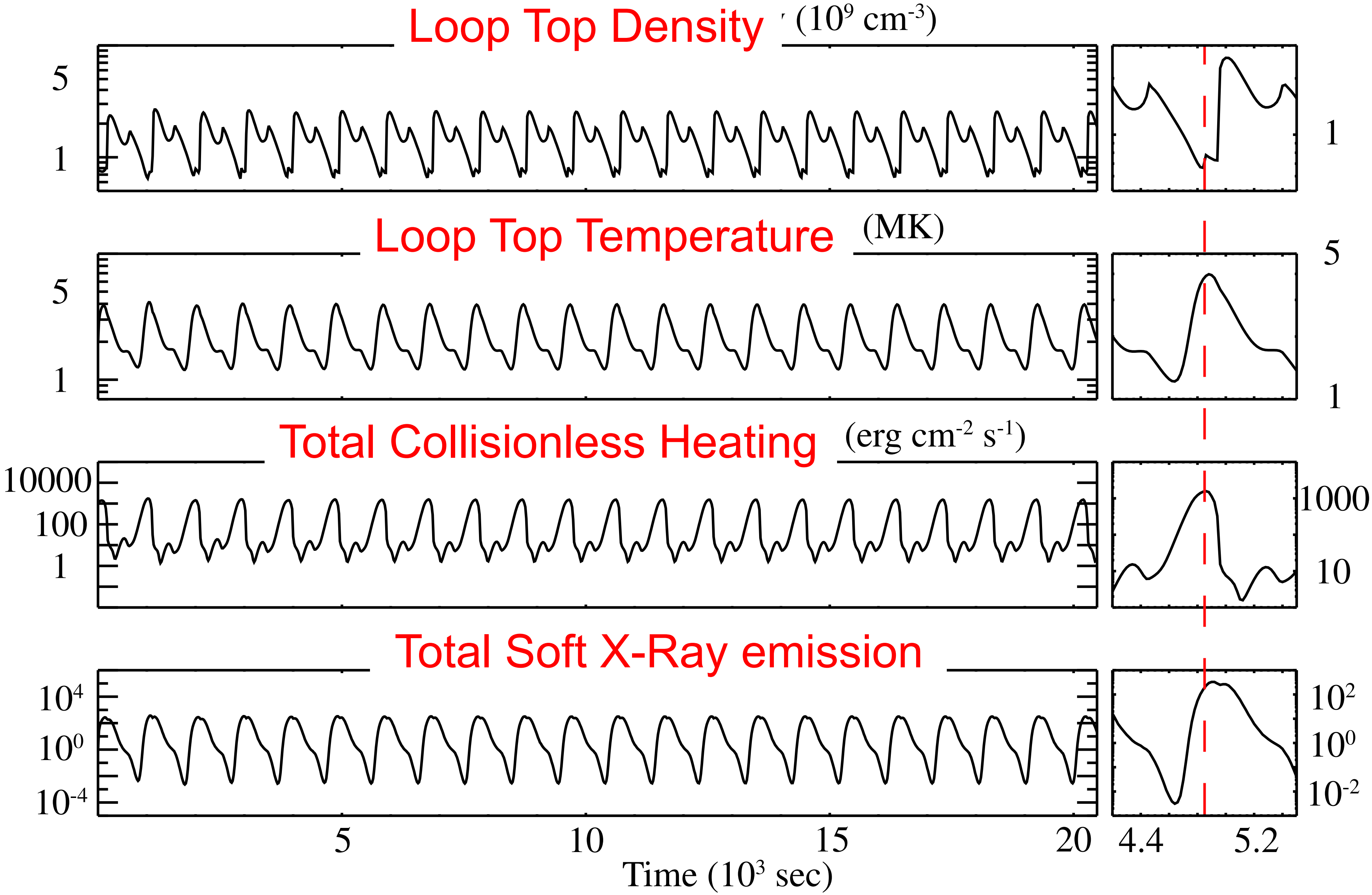
Velocity

Heating rate

Radiative Loss & Conduction



Long term calculation



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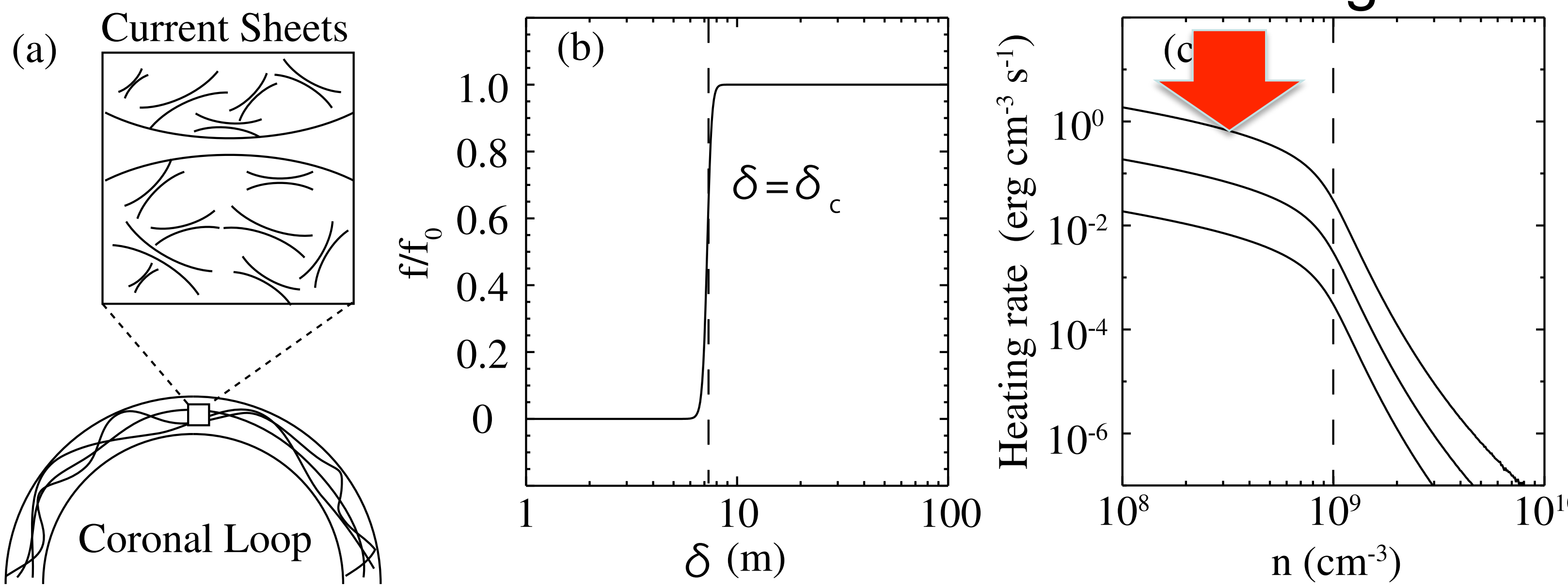

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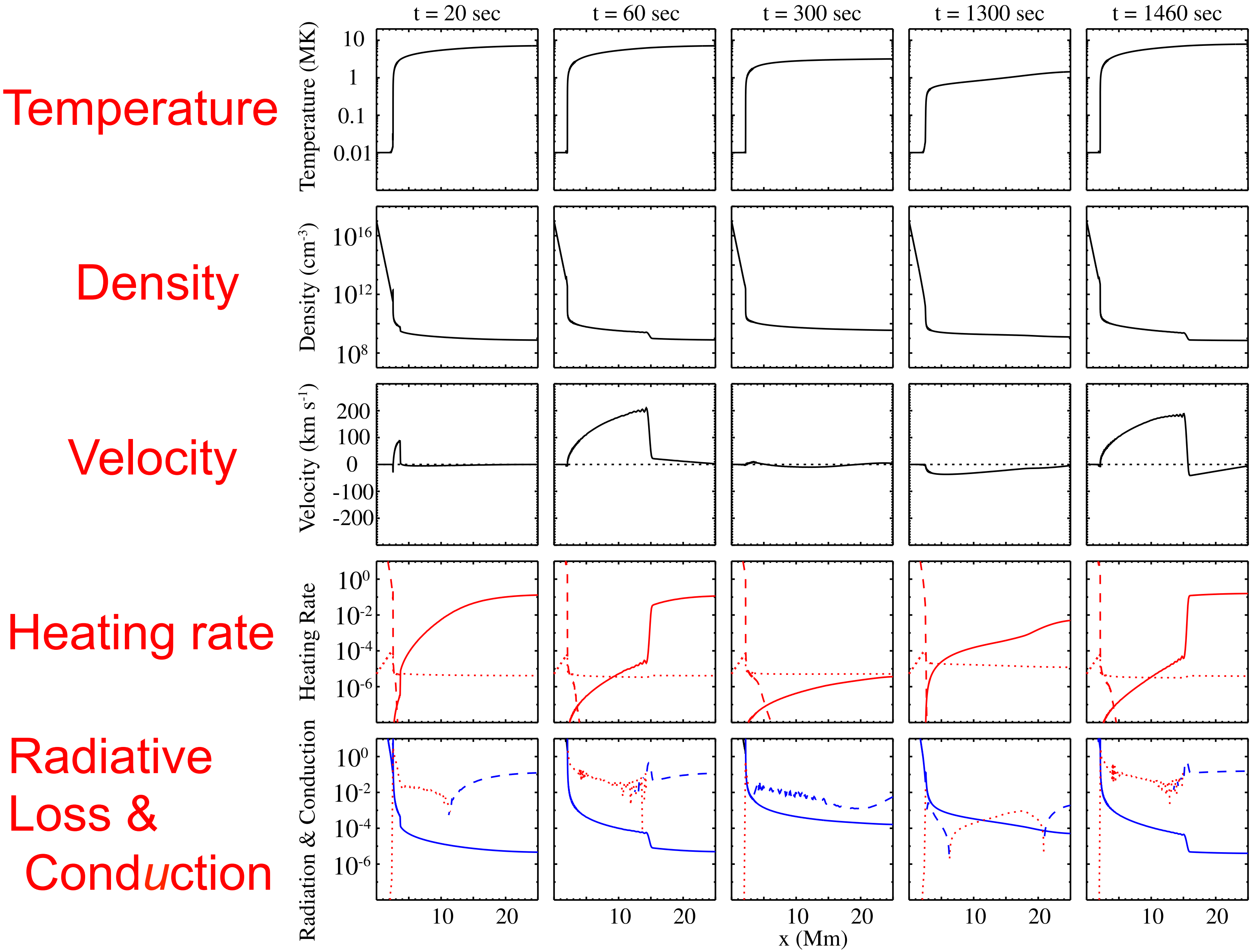
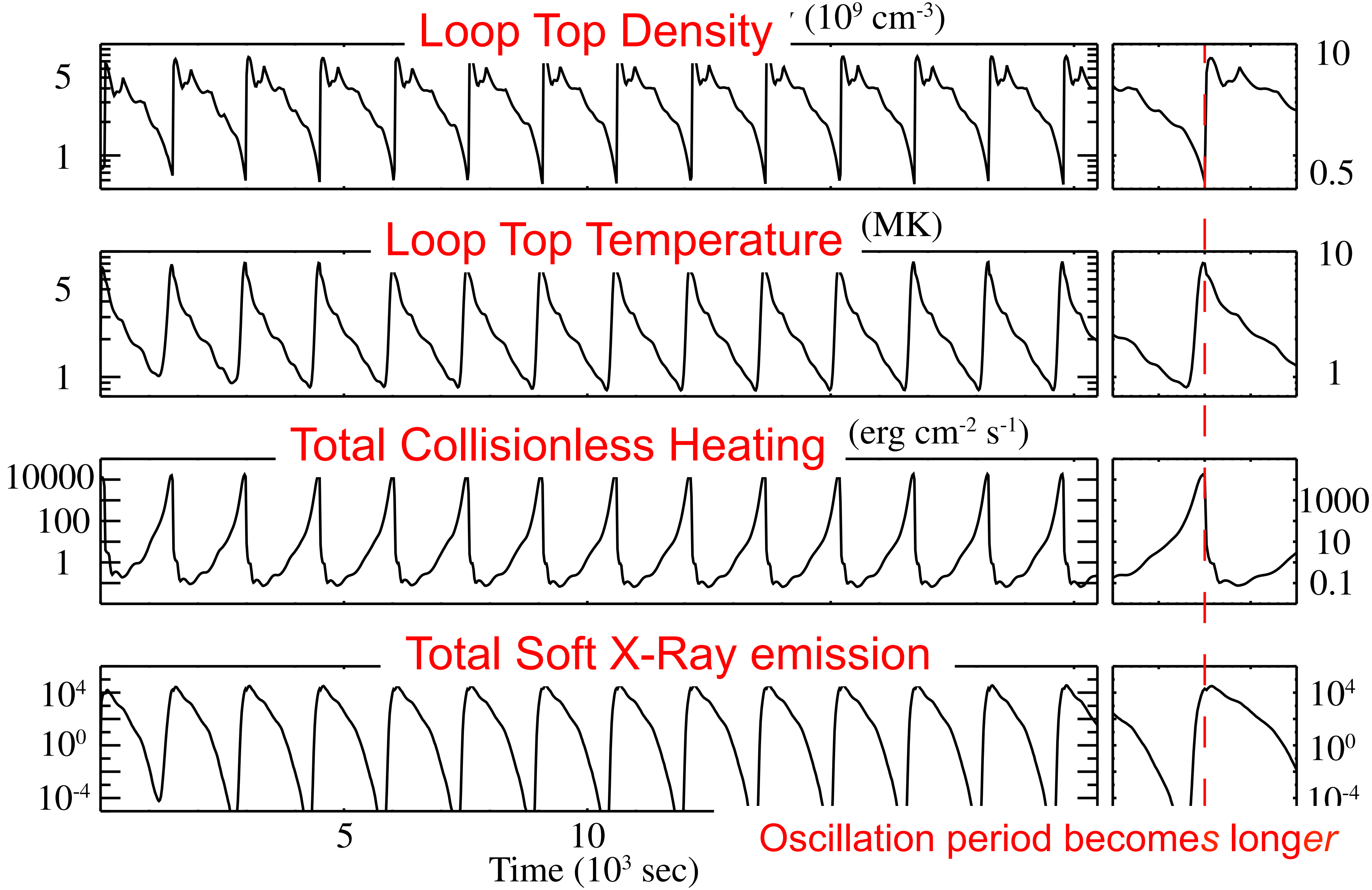
Strong heating: Flare

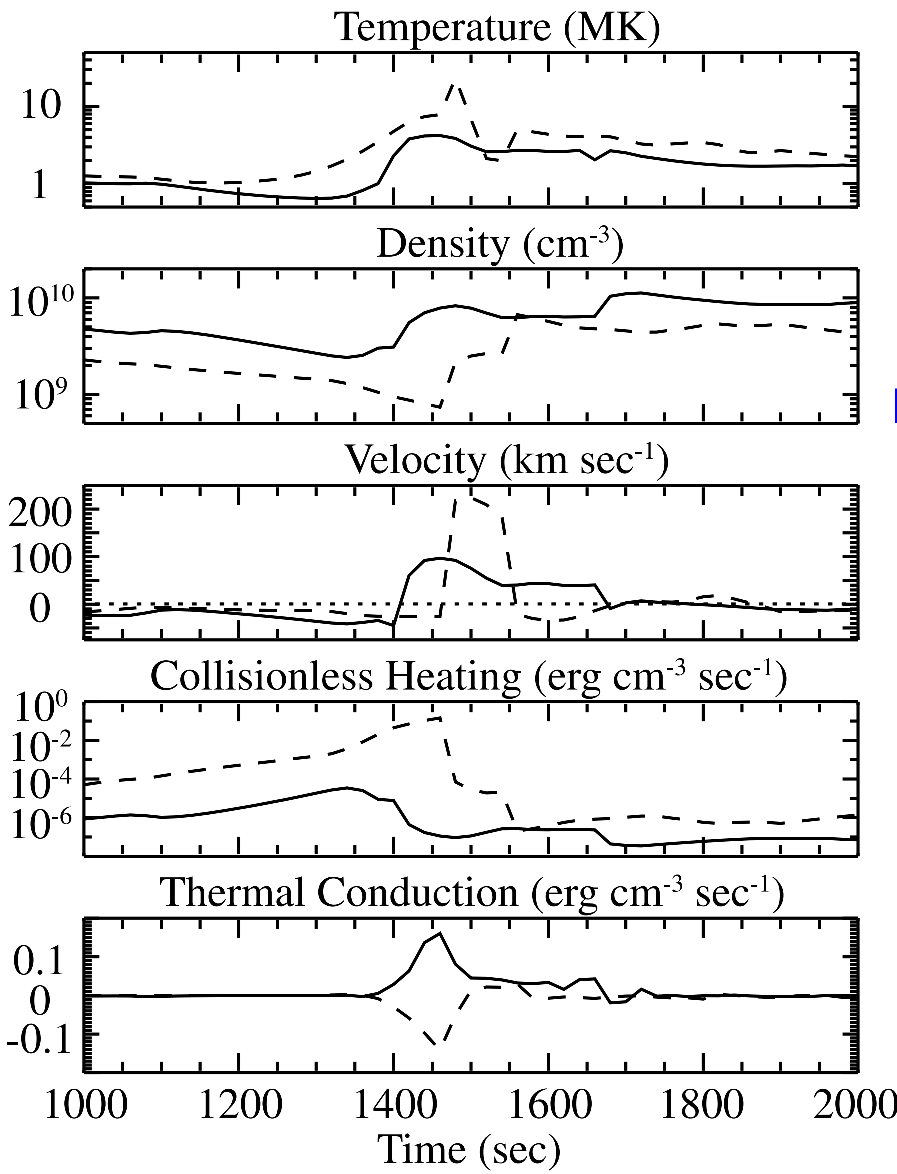


Long term calculation



Oscillation period becomes longer

What's Happened?

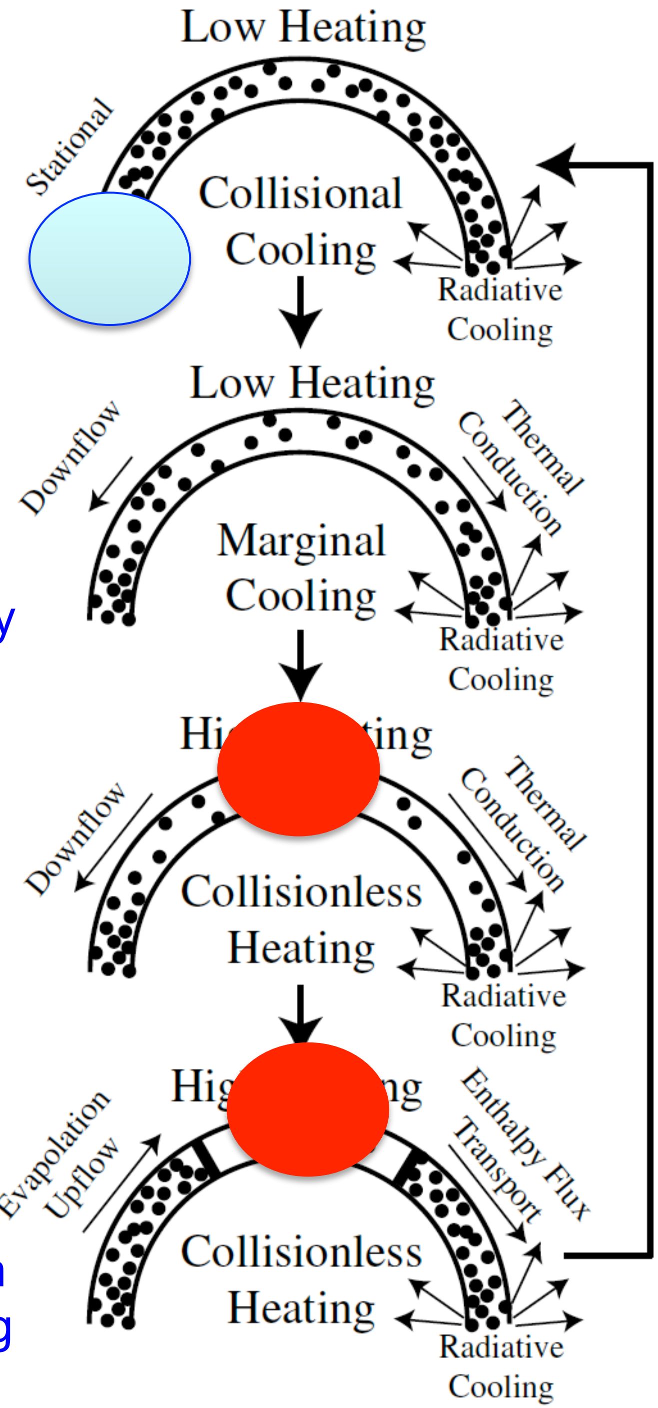


Radiative Cooling

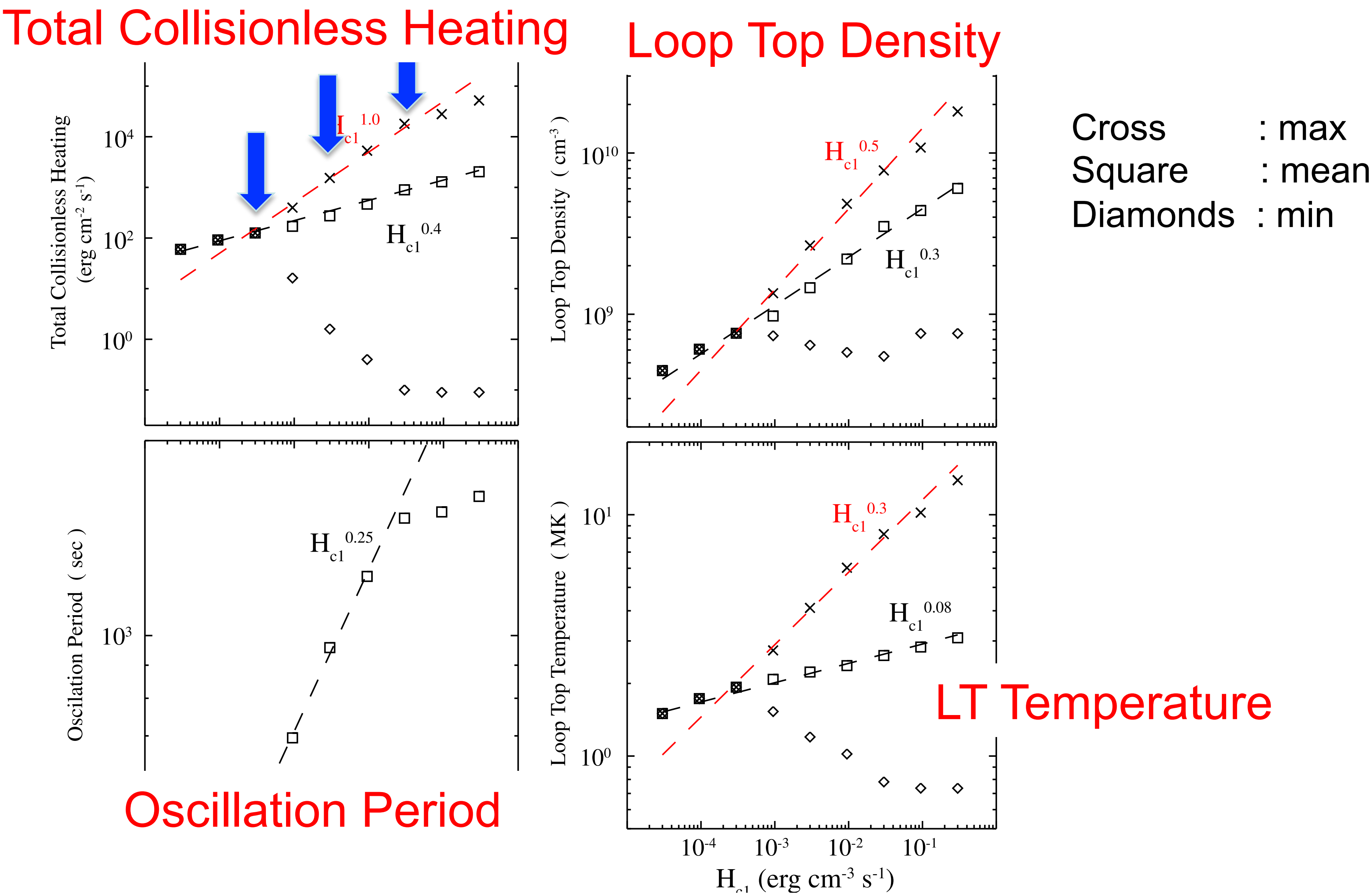
Draining
Reduce density

Heating On
gradP acc.

Evaporation
Stop heating



Parameter Survey



Conclusion

- **We studied coronal loop hydrodynamics including the regime transition from collisional to collisionless RX.**
- **We found two regime of behavior;**
  small amplitude heating → steady
  large amplitude heating → cyclic
- **On average the density of the loop system is close to the marginally collisionless value.**

Submitted to ApJ, “Self-organization of Reconnecting Plasmas to a Marginally Collisionless State”

Future work

- Comparison with Observation

  Warm loop (1MK) → cooling stage of cycle

  Hot loop (>2MK) → steady state

  Before flare → faint loop

  → downflow (~10 km/s)

- Modeling

  time dependent current sheet distribution

  time dependent ionization