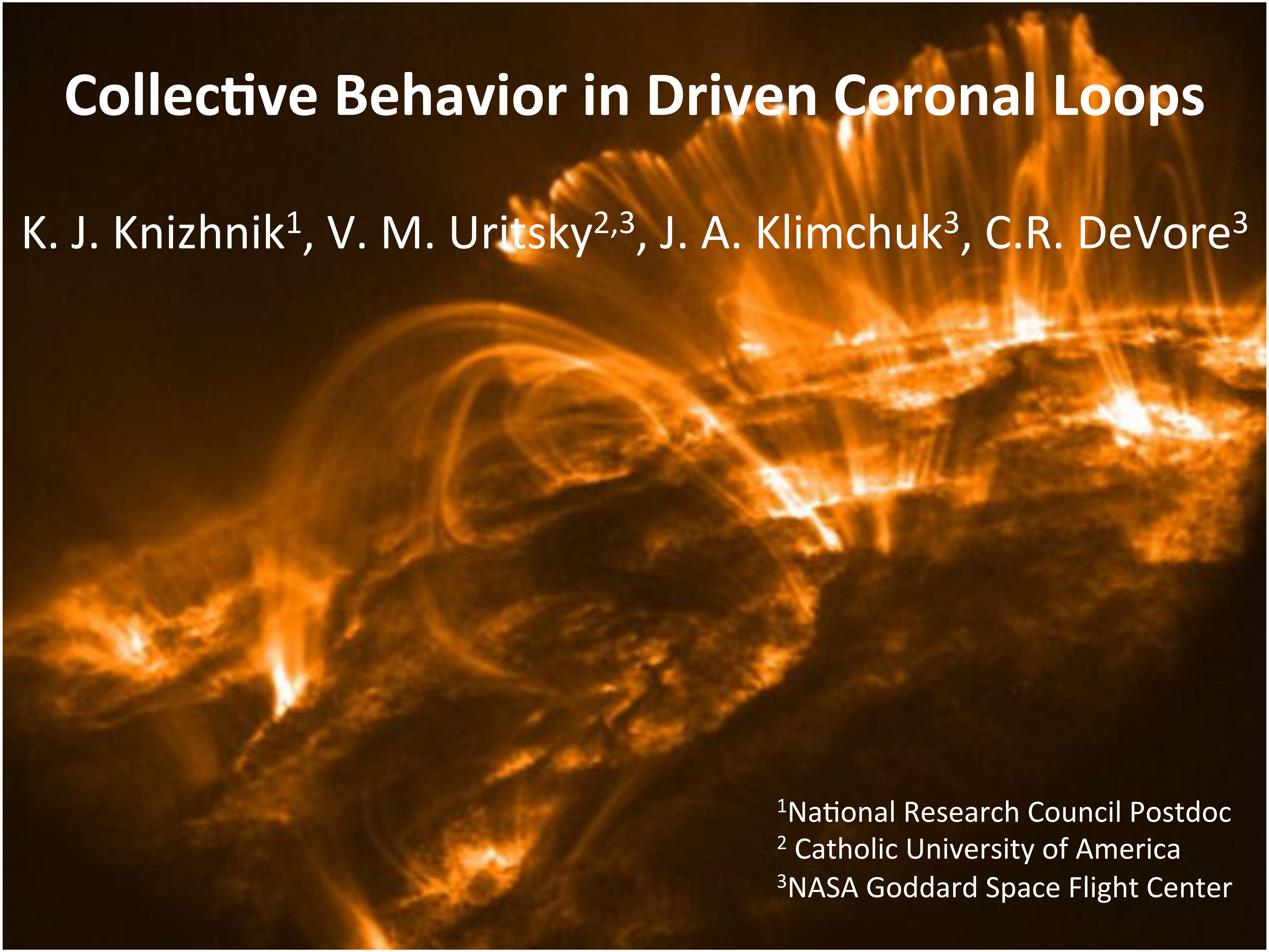
Collective Behavior in Driven Coronal Loops

K. J. Knizhnik[1], V. M. Uritsky[2,3], J. A. Klimchuk[3], C.R. DeVore[3]

[1]National Research Council Postdoc
[2] Catholic University of America
[3]NASA Goddard Space Flight Center



Background

- Solar corona is ultimately a driven system that consists of both a diffuse component and observationally distinct coronal loops.
- A loop is produced when many nanoflares occur in near proximity over a short period of time. The loop is a bundle of thin strands heated by a "nanoflare storm."
- Collective behavior is important for understanding two important properties of nanoflares---their frequency of occurrence and their spatial distribution.
  - If the delay between successive nanoflares on a given magnetic strand is much longer than a cooling time, the plasma cools fully before being reheated, and a wide range of temperatures are present in the time average (low frequency heating).
  - If the delay is much shorter than a cooling time, the temperature instead fluctuates about a nearly constant value (high frequency heating).
  - The spectrum of emitting radiation is vastly different in these two cases.

Collective Behavior

- Understanding collective behavior of many interacting current sheets is vital for understanding coronal heating.
- “Current sheet proliferation”
- In a driven system, behavior determined by driving and response of the system in the corona.
  - Ideal/quasi-ideal instabilities
  - Partial reconnection of flux tubes
  - Field line relaxation

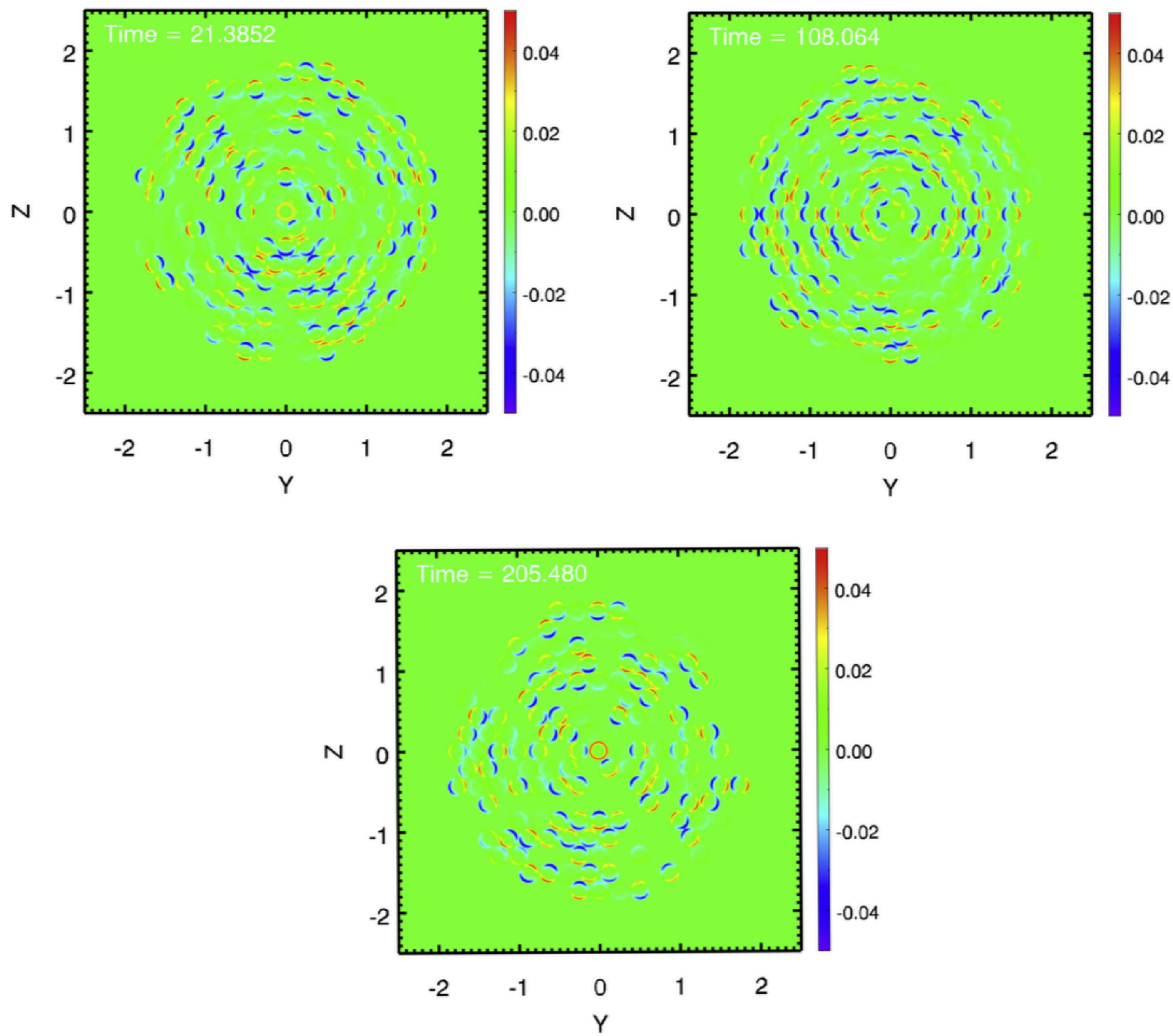


Figure 1. V_ϕ on the bottom plate near the beginning, middle, and end of the simulation. Red/yellow (blue/teal) represent counterclockwise/positive (clockwise/negative) velocity.

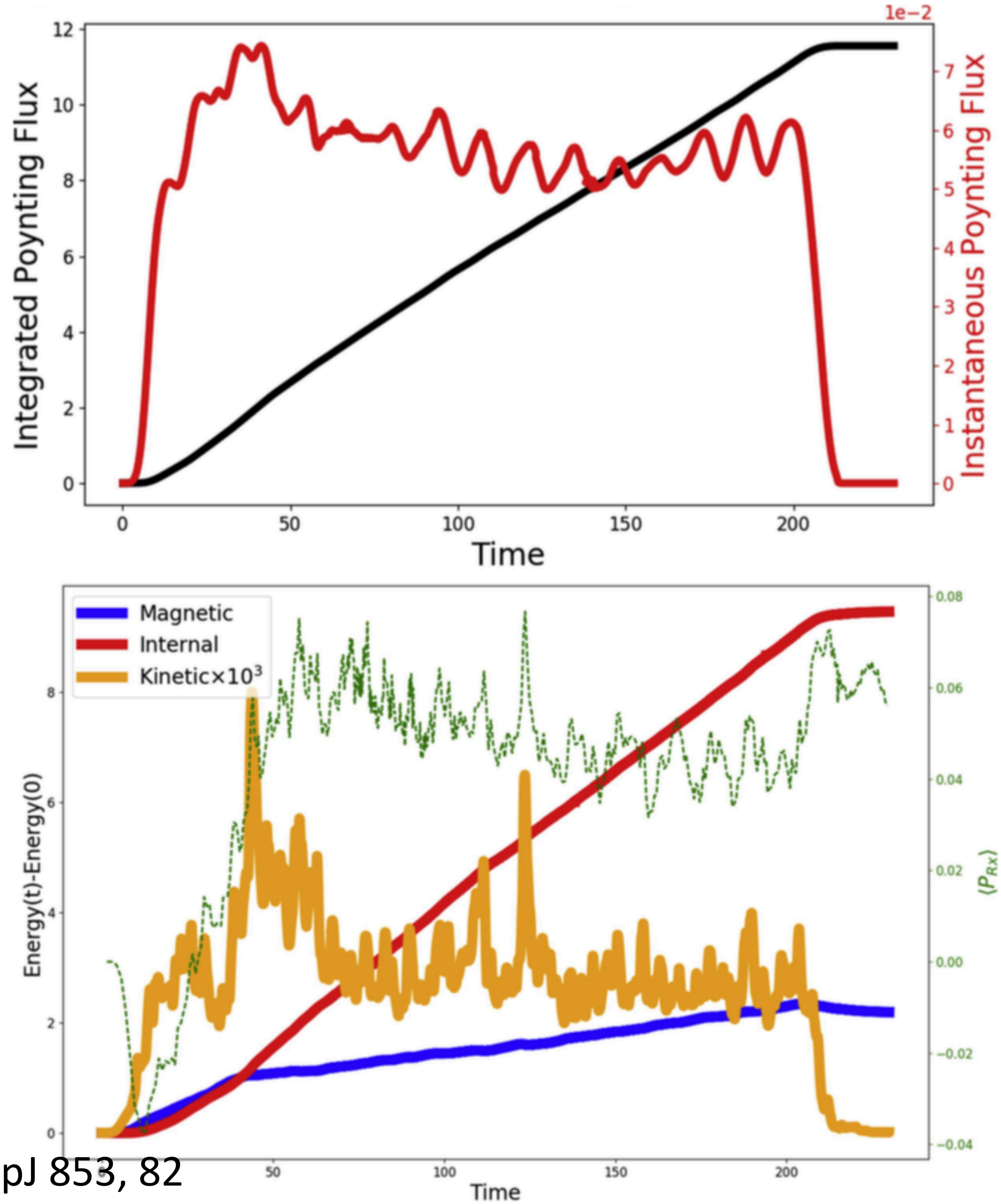


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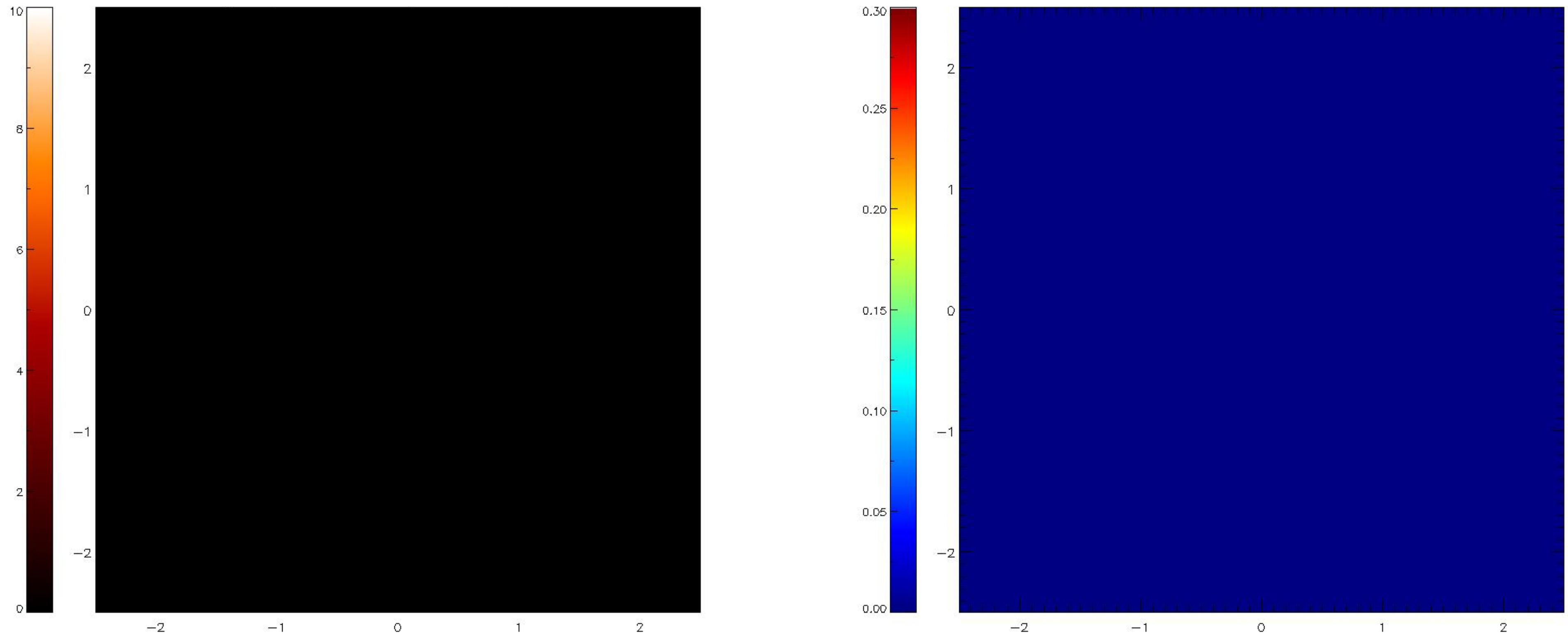
Figure 3. Top: instantaneous Poynting flux (red) and time-integrated Poynting flux (black). Bottom: evolution of magnetic (blue), plasma (red), and kinetic ($\times 10^3$; orange) energies as a function of time, as well as the energy conversion rate (dashed green).



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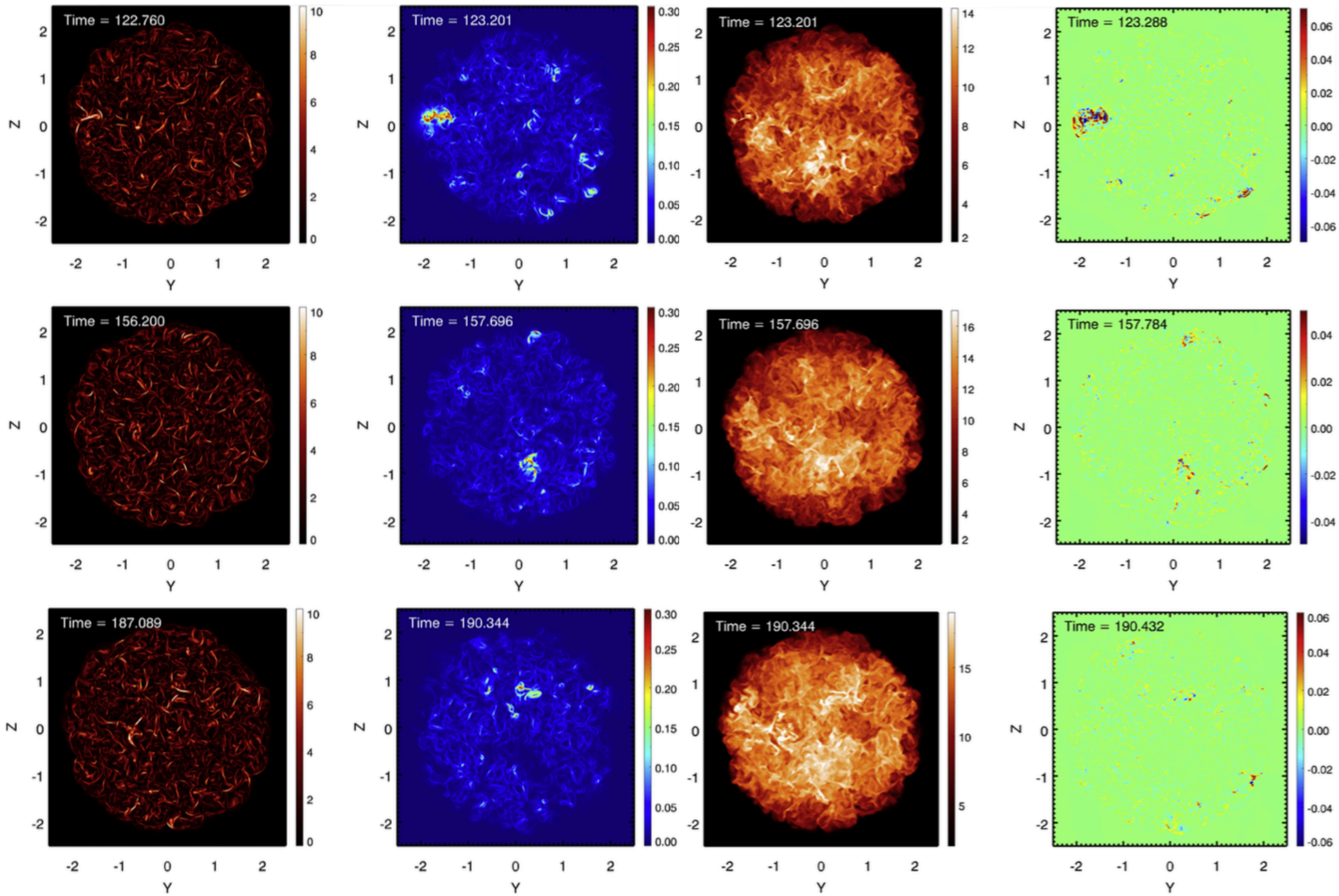

Figure 4. Left: current density in the midplane at three different times during the simulation. Right: S_h at times shortly after the current density frames. Left: temperature in the midplane at three different times during the simulation, corresponding to the maps of S_h above. The color scale is changir or the constant increase in temperature. Right: $\Delta T/T$ at the corresponding times.

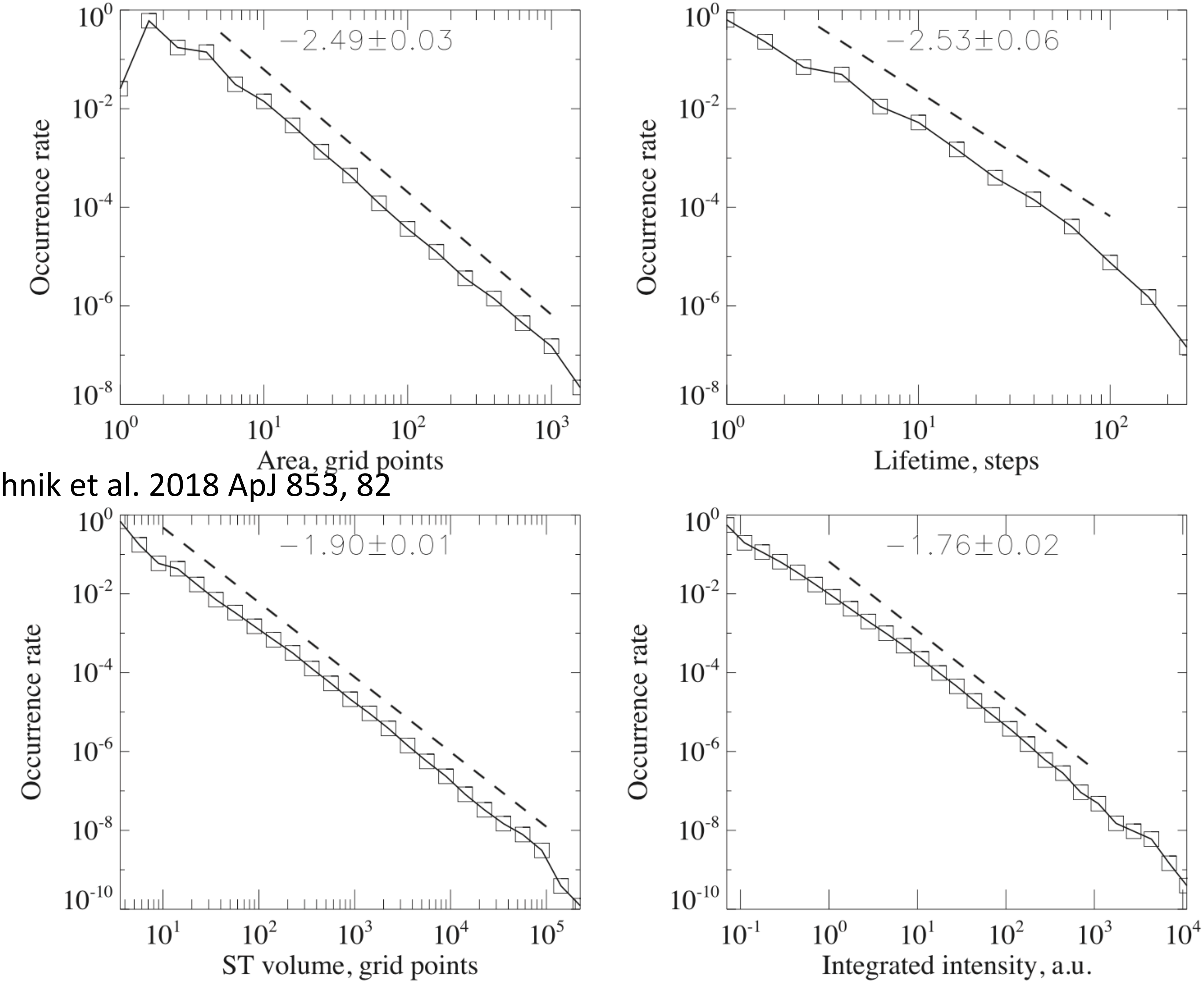

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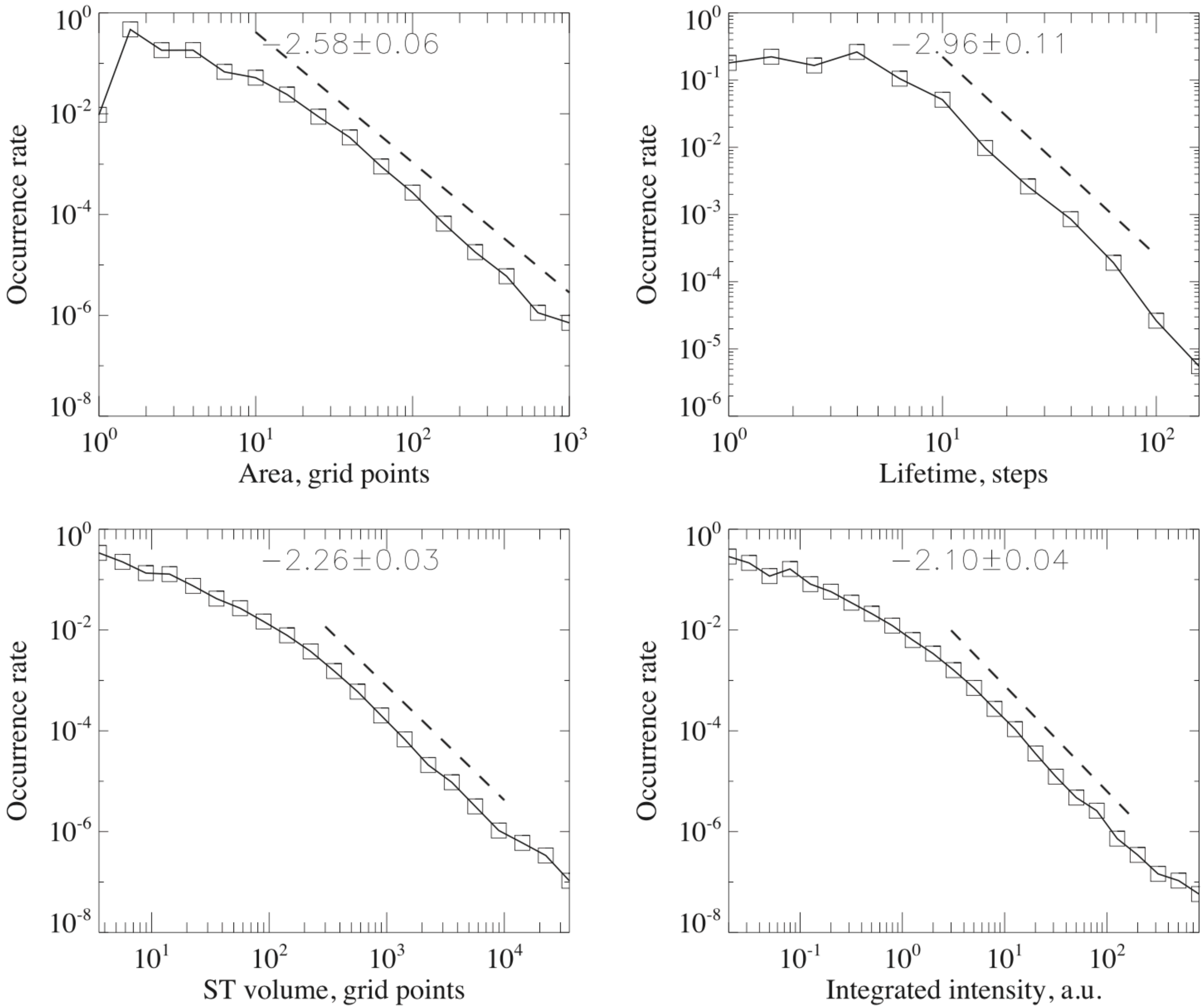
Figure 6. Probability distribution of temperature difference ΔT as a function of area (top left), time (top right), area+time (bottom left), and energy (bottom right).



igure 7. Probability distribution of horizontal Poynting flux as a function of area (top left), time (top right), area+time (bottom left), and energy (bottom right).

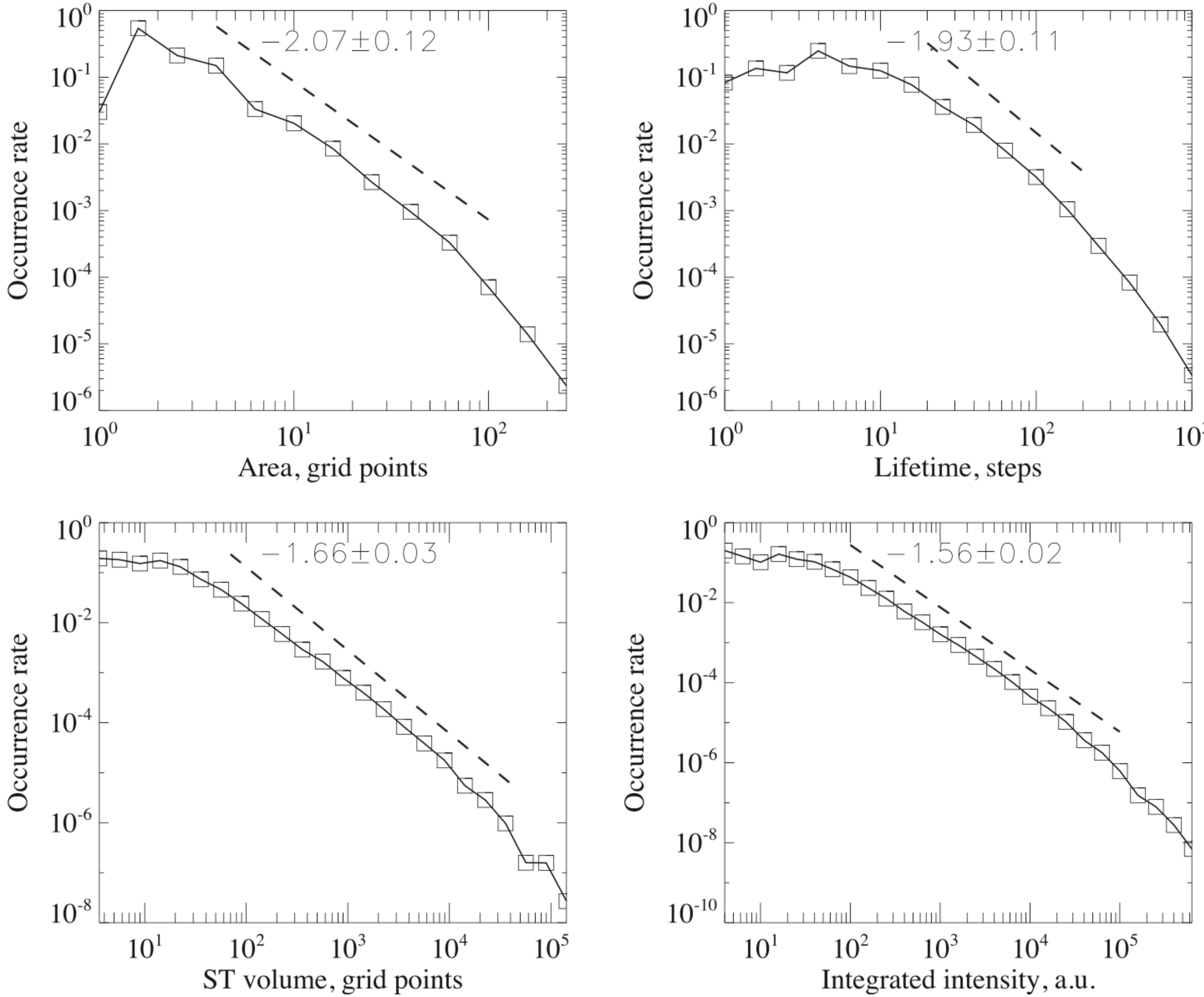


Figure 8. Probability distribution of current density as a function of area (top left), time (top right), area+time (bottom left), and energy (bottom right).

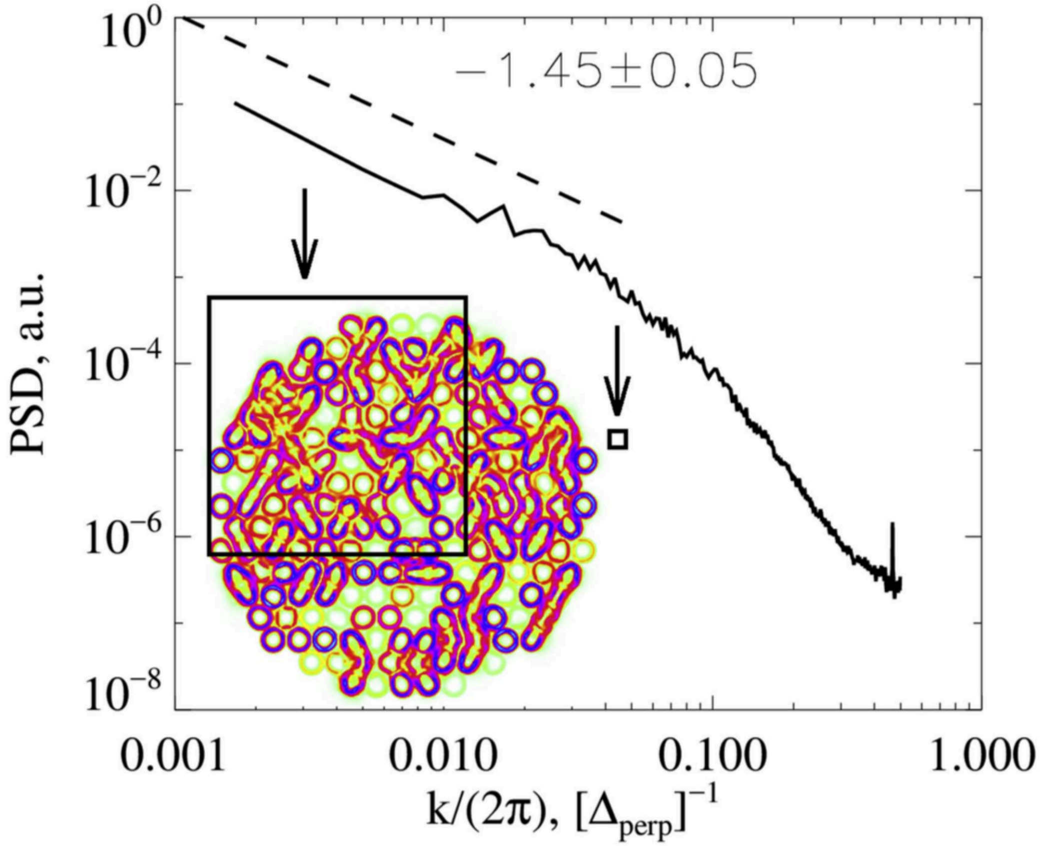
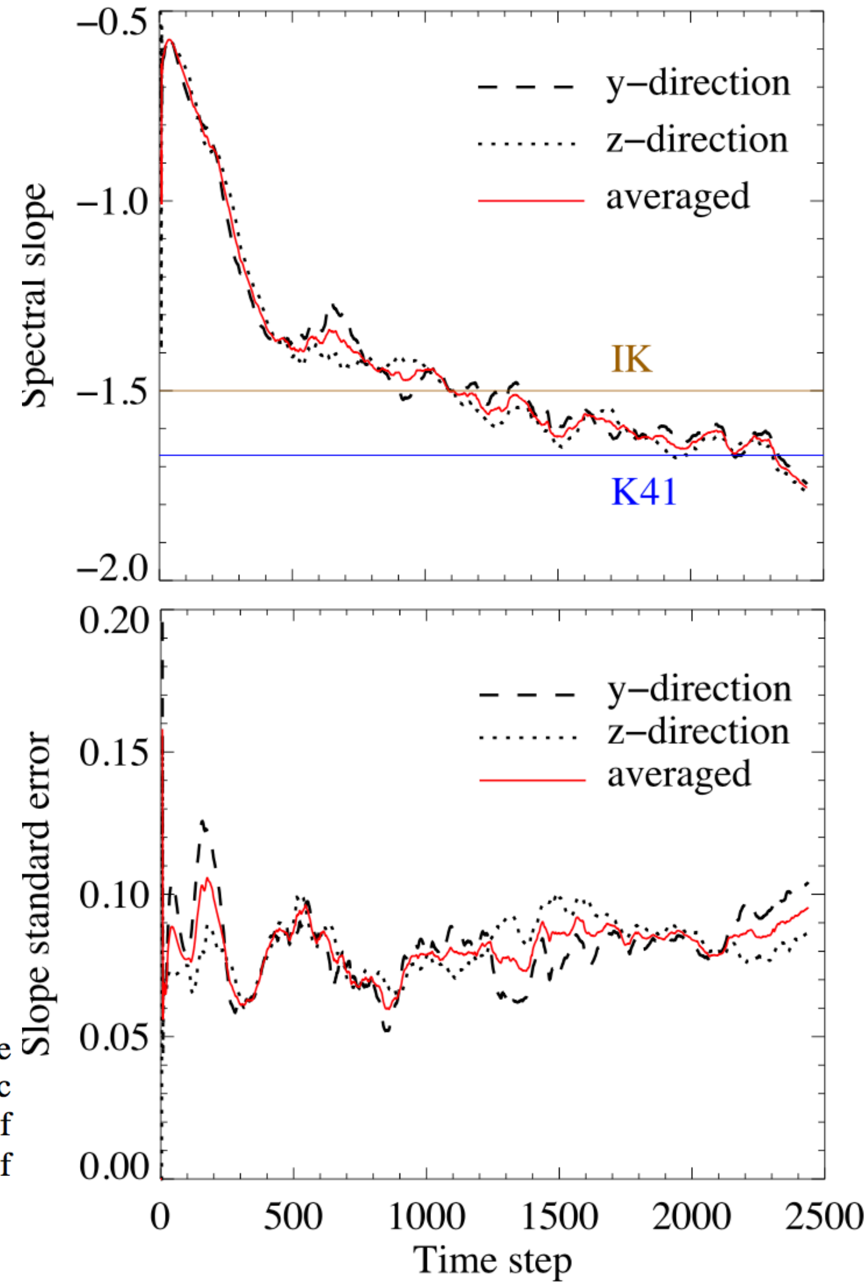


Figure 9. Probability distribution of the magnetic field for the last half of the simulation, along with a rendering of the 2D cut of the transverse magnetic field at the end of the simulation. The big box shows the approximate scale of $\Delta_{\rm perp}^{-1} = 0.003$, while the little box shows the approximate scale of $\Delta_{\rm perp}^{-1} = 0.04$, where there is a break in the spectrum.



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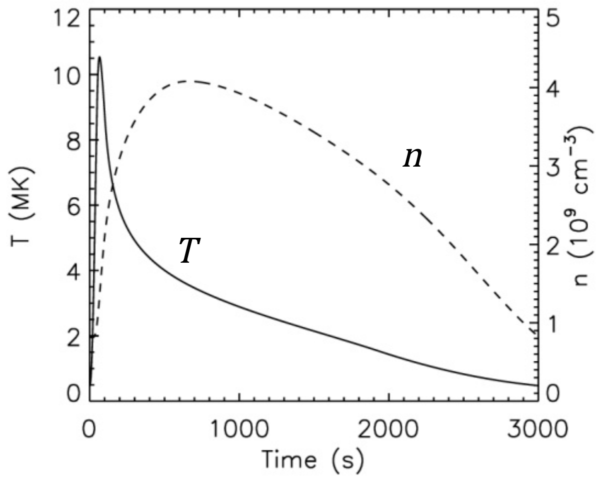
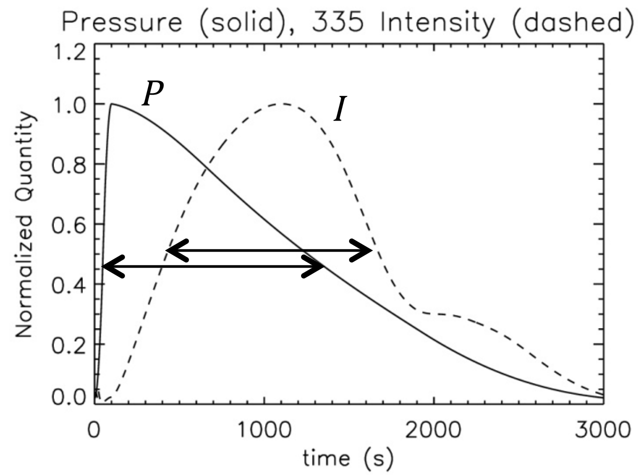
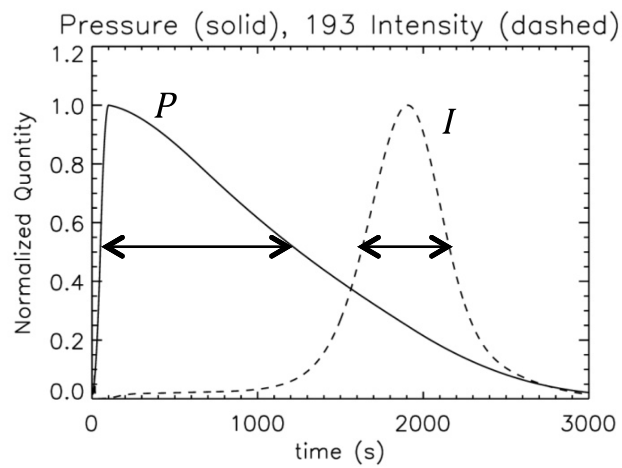
Nanoflare-Heated Strand

(EBTEL Simulation)







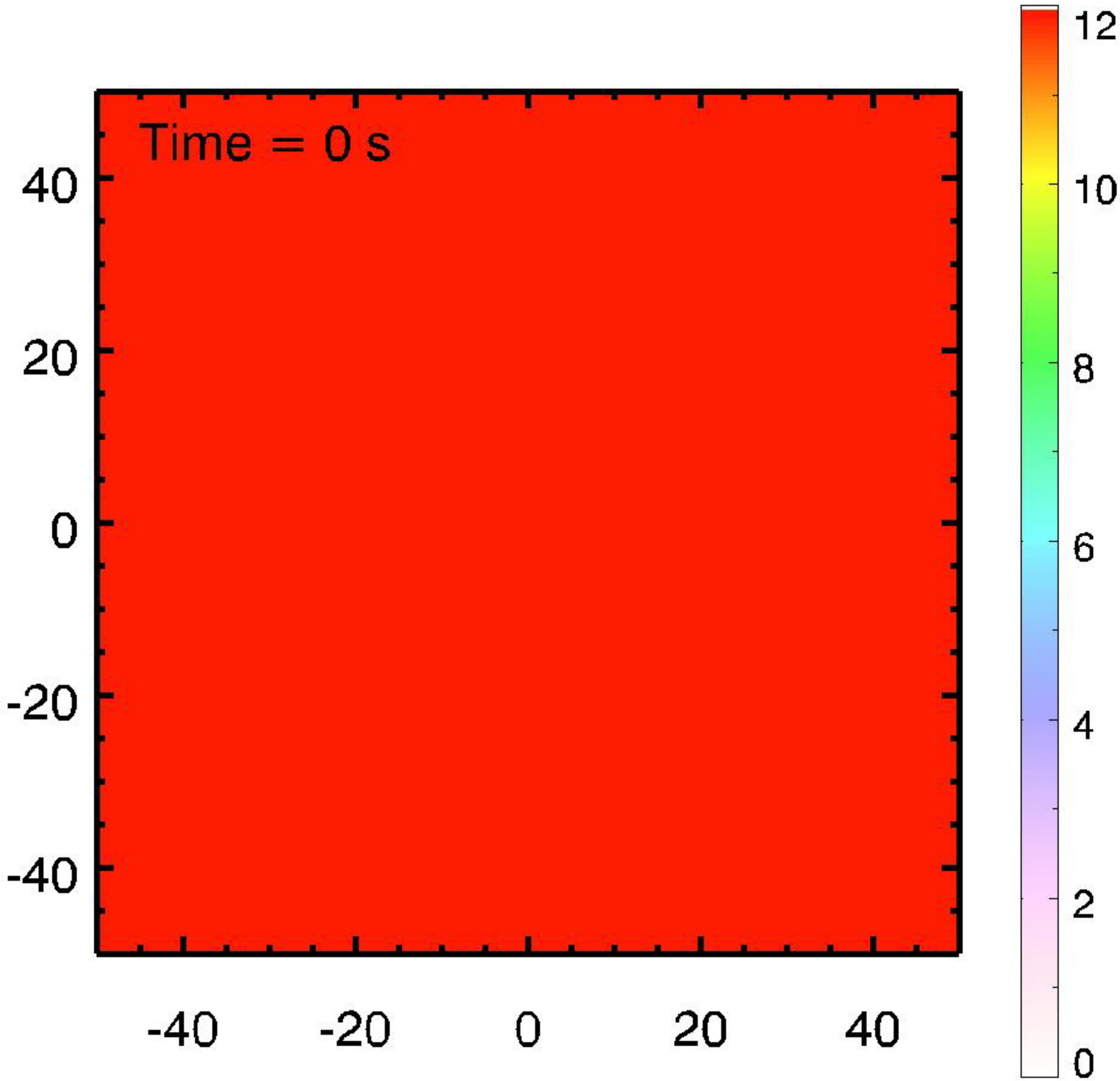
Pressure is a “reasonable” proxy for intensity.

Duration is about right.

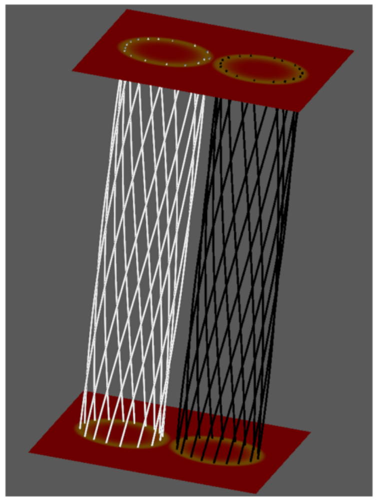
Delay not critical (similar for all tubes)

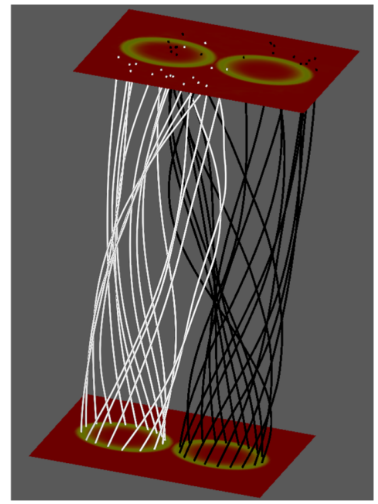
Simple cooling model

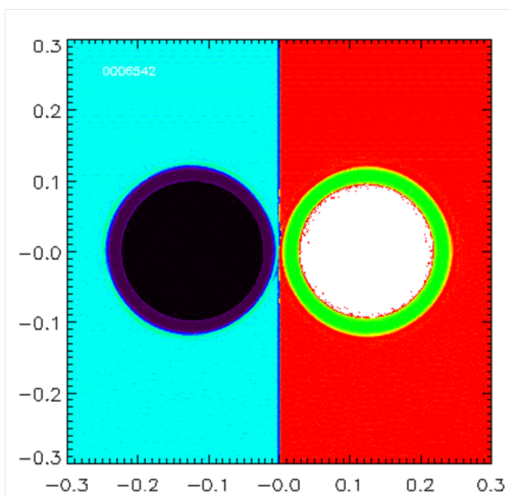
- Integrate pressure along each field line in MHD simulation.
- Apply 'cooling' to each field line that depends on instantaneous pressure and temperature.
- Identify bundles of 'hot loops'.
- P_new(i) = P_new(i-1)*exp(-dt/tau(i-1)) +DeltaP_old
- tau(i) ~ T(i)^2.5/P_new(i)

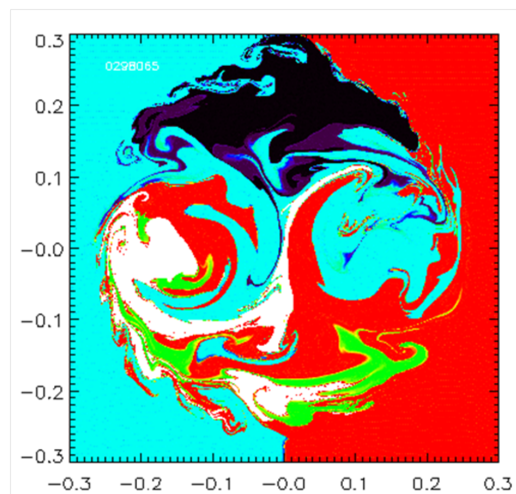

Time = 0 s
40
20
0
-20
-40
-40
-20
0
20
40
12
10
8
6
4
2
0

Two Vortex Cells Driven at Boundary









Future Plans

- Analyze statistics of ‘cooled’ loops.
- Move analysis to full 3D volume.
- Where along loops is most of the heating occurring?
- Analyze how complex current patterns get created for just two interacting flux tubes.