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Effects of a Velocity Shear on Explosive Phases of Double Tearing Modes

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Introduction and Motivation

- Magnetic reconnection is a ubiquitous phenomenon in astrophysical and laboratory plasmas.

- The "plasmoid instability" occurring in elongated current sheets greatly enhances the reconnection rate beyond what has been predicted by the Sweet-Parker and Petschek scaling relations

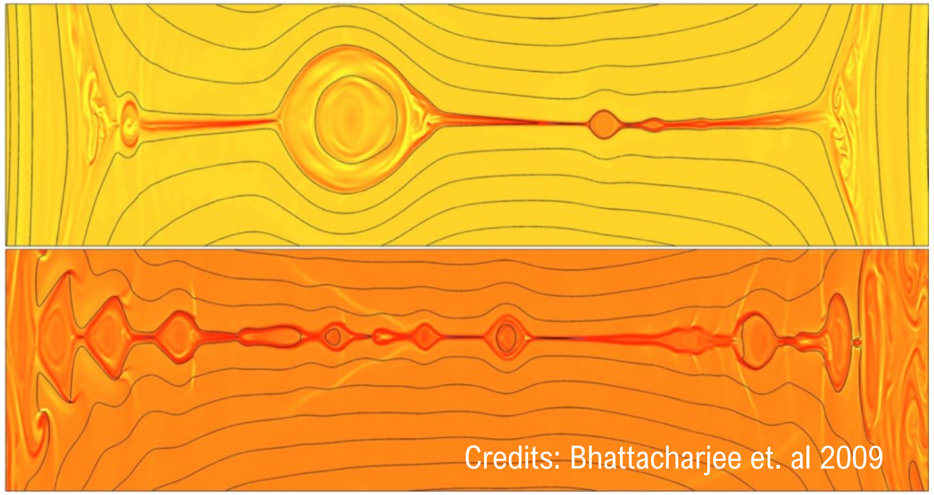
  (Bhattacharjee et. al, 2009; Parker, 1957 ; Petschek, 1964, Comisso et.al. 2017)

- Multiple current sheet systems are prevalent in the Heliospheric domain and as such, its simplification in the form of a Double Tearing Mode (DTM) has been known to exhibit a fast structure-driven non-linear growth phase.

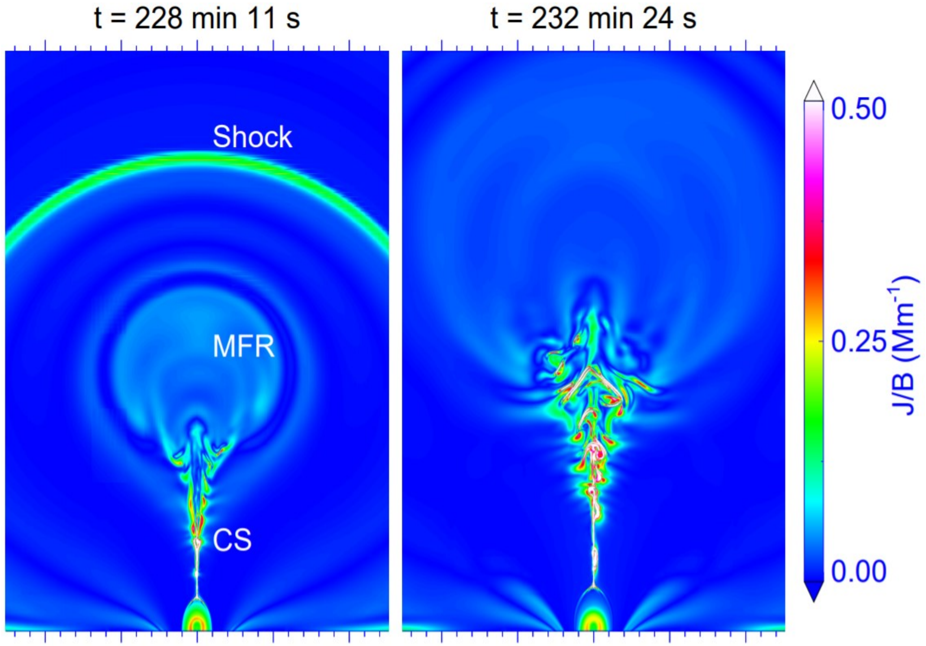
  (Janvier, 2011)

- We investigate the evolution of an 'Ideal' high Lundquist number double current sheet system exhibiting plasmoid instability and study the effects of a velocity shear on the dynamics of such systems.

- We also investigate the various particle acceleration mechanisms by introducing test particles in these systems to explore the role of such an explosive evolution in the production of suprathermal particles that are commonly observed in the reconnection regions (solar flares, solar wind etc.).



Credits: Bhattacharjee et. al 2009



Credits: Jiang et. al. 2021

Methodology

- Initial setup is a DTM evolved by a system of standard resistive-MHD equations using the PLUTO code (Mignone 2007).
- The applied resistivity set the Lundquist number of the system at 9 x 10^6 .
- The magnetic fields, velocity and density are prescribed as shown on the right with B_0 set to $\sqrt{2}$. The value of V_s was varied from zero to 1.25 times the Alfven speed of the system.

$$B_x(y) = B_0 \left[tanh\left(\frac{y-l}{w_B}\right) - tanh\left(\frac{y+l}{w_B}\right) + 1 \right]$$

$$\rho(y) = sech^2\left(\frac{y-l}{w_B}\right) + sech^2\left(\frac{y+l}{w_B}\right) + 1$$

$$v_x(y) = v_s \left[tanh\left(\frac{y-l}{w_v}\right) - tanh\left(\frac{y+l}{w_v}\right) + 1 \right]$$

Fig 1: *A snapshot of the initial density configuration in the domain (fig shows a small portion of the whole domain) showing a double Harris sheet configuration*

TABLE I. Setup names for various shear speeds.

Shear (v_s/v_A)	0.0	0.25	0.5	0.75	1.0	1.25
Setup Name (Fluid)	S0	S25	S50	S75	S100	S125
Setup Name (Particles)	SP0	-	-	SP75	-	-

Results

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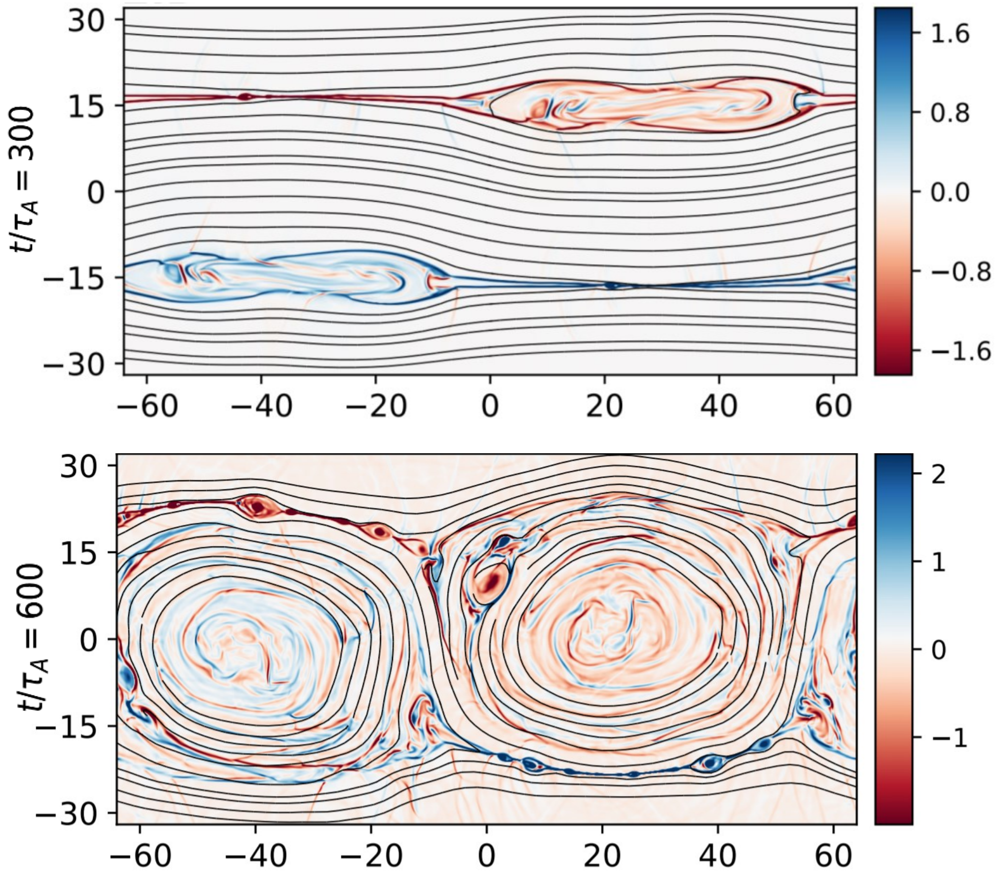

Fig 2: *Time evolution of the S25 setup where the panels show current density **J** overplotted by magnetic field streamlines.*

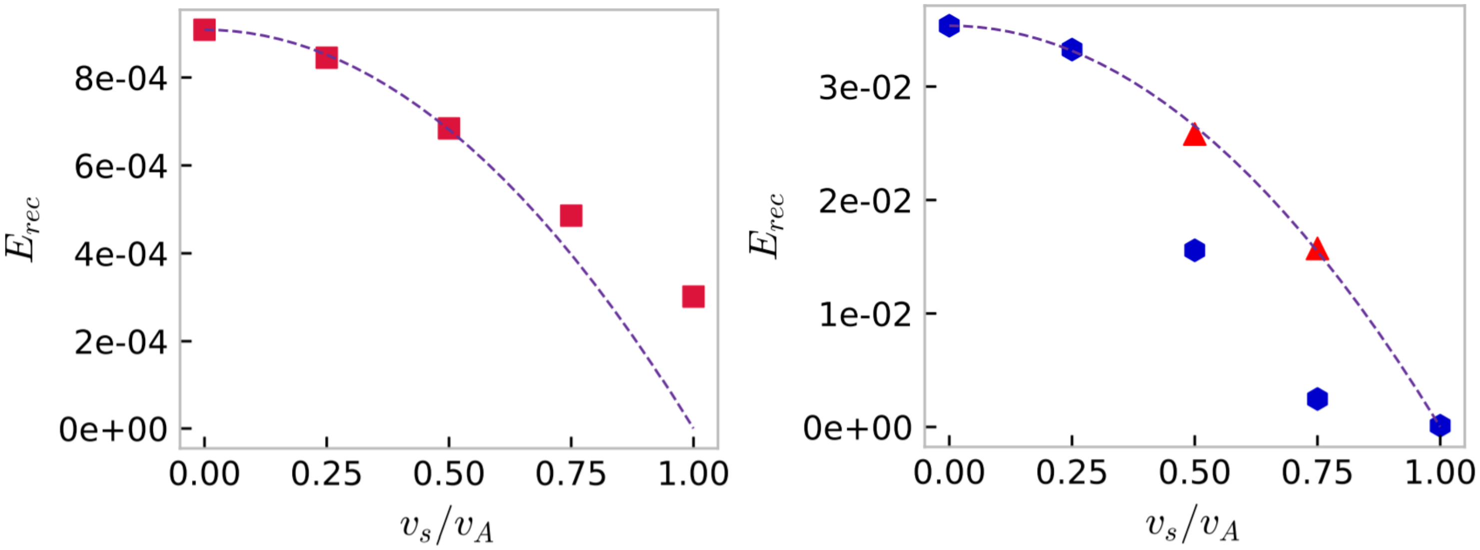

Fig 3: *The variation of the reconnection rate of the system with shear flow during the slow growth phase (left panel) and the explosive phase (right panel). The dashed lines correspond to the theoretical scaling given by Cassak and Otto* (Cassak, 2011) *The blue hexagons on the right panel correspond to the measurement of the reconnection rate during the same time period whereas the red triangles correspond to the measurement at different times when the island widths of the systems are similar.*

- The theoretical scaling given by Cassak and Otto (Cassak, 2011) for the variation of the reconnection rate with shear for a single sheet remains valid even during the explosive phase of the DTM if the reconnection rate of the system is measured at different times when the island widths of the systems are similar.

Results

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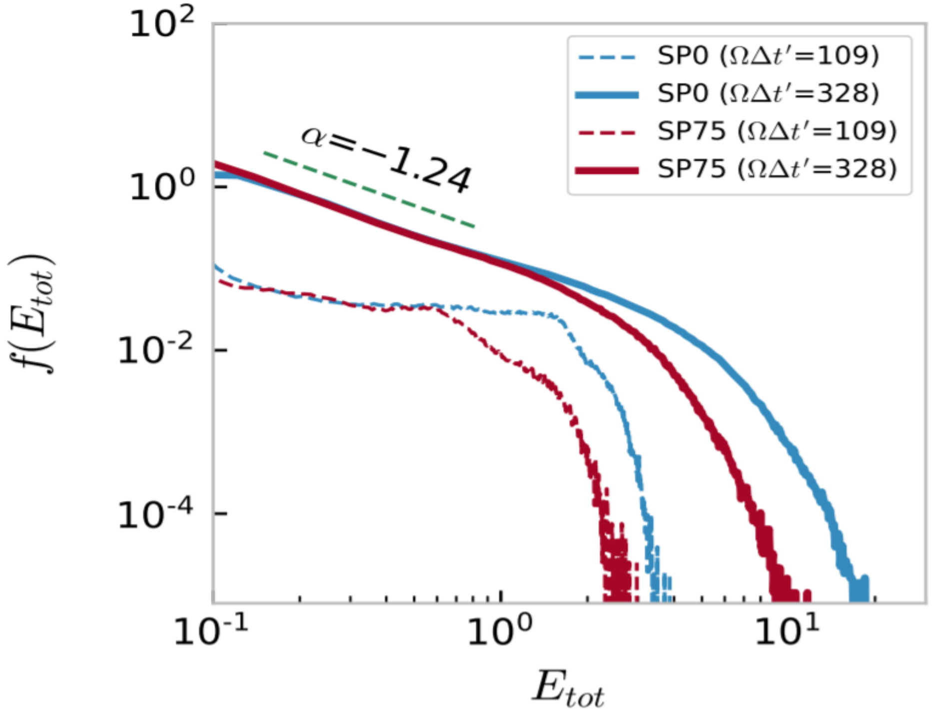

Fig 4: *The normalized energy spectrum of the particles injected during the explosive phase. $\Omega\Delta t'$ corresponds to the integration time of the particles in the evolving fluid background.*

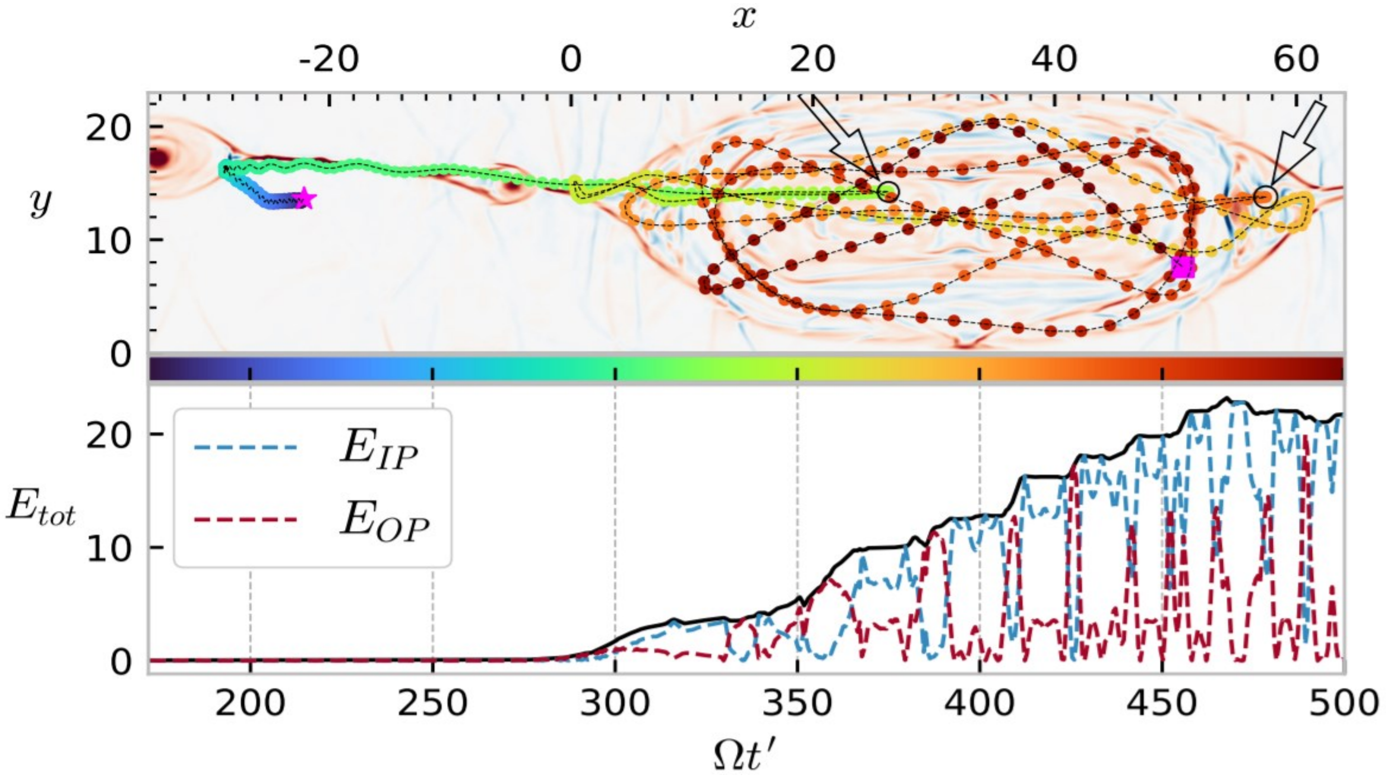

Fig 5: *The trajectory (top panel) of a highly accelerated particle from the SP0 setup. The arrows show the locations where the particles suffer a nearly head-on reflection from the reconnection exhaust fronts. The bottom panel shows the energetics where E_{IP} is the in-plane energy and E_{OP} is the out-of-plane energy and the color-bar represents time.*

- The presence of a shear has no effect on the power law index of the energy spectrum, but it truncates the high energy exponential tail at a lower value.
- The island dynamics play a crucial role in energizing the particles as they gain a significant amount of energy when reflecting from the fast-moving exhaust fronts and the particles that don't suffer such collisions do not energize as much.

Summary and Conclusions

- We have tested the scaling of the reconnection rate with shear in the context of plasmoid dominated explosive reconnection in high Lundquist number double current sheet systems.
- The theoretical scaling during the early phases of evolution and even remains true during the explosive plasmoid dominated phase of a double current sheet system if the reconnection rate is measured when the primary island widths are similar.
- The presence of a shear flow has negligible effect on the spectral index of the particles; however, it truncates the exponential tail at a smaller value due to less efficient acceleration.
- The scattering of the particles from the reconnection exhaust fronts are a significant contributor to the overall energization.
- Transient phenomena such as plasmoid motion and island dynamics play a crucial role in particle energization and their effects can only be captured by employing a fluid background that is evolving with the particle.

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