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Comment on “Nonideal Fields Solve the Injection Problem in Relativistic Reconnection”

Fan Guo, Qile Zhang, William Daughton, and Hui Li
*Los Alamos National Laboratory, Los Alamos, NM 87545, USA**

Xiaocan Li and Yi-Hsin Liu
Dartmouth College, Hanover, NH 03755, USA

Omar French
Department of Physics, 390 UCB, University of Colorado, Boulder, CO 80309, USA

William Matthaeus
Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA

Patrick Kilian
Space Science Institute, 4765 Walnut St, Suite B, Boulder, CO 80301

Grant Johnson
Princeton Plasma Physics Laboratory 100 Stellarator Rd, Princeton, NJ 08540

Sironi [1, (S22)] reported the correlation between high-energy particles and their crossings of regions with electric field larger than magnetic field ($E > B$ regions) in kinetic simulations of relativistic magnetic reconnection [2–8]. They claim that $E > B$ regions (for vanishing guide fields) accelerate particles to the injection energy $\gamma_{inj} \sim \sigma$ (magnetization). S22 shows that if test-particles are reset to low energies in $E > B$ regions, injection is suppressed. We reexamine these claims using a simulation resembling the reference case in S22 with no guide field. We show that $E > B$ regions contribute very little to injection ($\sim 10\%\gamma_{inj}$) as they only host particles for a short duration. The energization *before* any $E > B$ crossings has a comparable contribution, indicating $E > B$ regions are not unique for pre-acceleration. A new test-particle simulation that zero-outs $\mathbf{E}$ during $E > B$ does not strongly influence injection. We suggest that the procedure to exclude $E > B$ acceleration in S22 partly removes acceleration outside $E > B$, leading to a false conclusion.

We initialize a force-free layer [1, 6] with the reconnecting-field-magnitude B_0 and half-layer-thickness $\lambda = 6d_e$ (skin depth). We focus on the zero-guide-field case, and refer readers to [11] on guide-field effects. We use $\sigma = 50$ and temperature $kT = 0.36m_ec^2$, and have confirmed our conclusion holds when varying them. The dimension is $L_x \times L_z = 1600d_e \times 1200d_e$ and the simulation lasts $2.5L_x/c$ (same as S22). We added a perturbtion to trigger reconnection and removed the initial current-sheet contributions for all analyses. Each d_e is resolved by 4 cells with 100 positron-electron-pairs per cell. Boundaries are periodic in the x-direction and conducting (reflecting) in the z-direction for fields (particles). We uniformly select and trace 1.28 million particles and

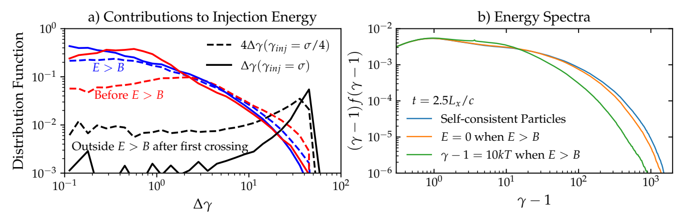

FIG. 1. a) Distributions of energy gain for $E > B$ particles during injection: in $E > B$ regions, before $E > B$ crossing, and outside $E > B$ regions after the first crossing; b) Spectra for self-consistent particles, test-particles with $E = 0$ when $E > B$, and test-particles with energy reset to $10kT$ when $E > B$ (resembling S22).

record the electromagnetic fields they experience every time-step [9].

During injection of each particle before it reaches $\gamma = \sigma(\sigma/4)$, 79.4%(53.7%) of injected tracers have $E > B$ crossings (“$E > B$ particles”). S22 finds a stronger correlation, since they label all particles that ever crossed $E > B$ regions during the entire simulation [10]. Clearly, a significant fraction of particles are injected without needing $E > B$ [11]. Nevertheless, it is still interesting to explore if $E > B$ regions are important for $E > B$ particles.

During injection, $E > B$ particles can have multiple $E > B$ crossings. Our analysis includes all the duration when particles experience $E > B$. This time constrains the acceleration in $E > B$ regions $\Delta\gamma_{E>B} \lesssim \int qrB_0cdt/(m_ec^2)$, where reconnection rate $r \sim 0.1$ [12–16]. For $\sigma = 50$, $\omega_{pe}t_{inj} \gtrsim 50(12.5)$ is needed for $\gamma_{inj} = \sigma(\sigma/4)$. However, the mean time that particles stay in $E > B$ regions is $\omega_{pe}\bar{t} = 4.3(1.9)$ for $\gamma_{inj} = \sigma(\sigma/4)$ and nearly *no* $E > B$ particles have time for injection. Fig. 1a shows the distributions of particle energy gain (before reaching γ_{inj}) in $E > B$ regions, before any $E > B$ crossings, and outside $E > B$ regions after the first $E > B$ crossing. The acceleration in $E > B$ regions is insufficient for direct injections, with $\Delta\bar{\gamma}_{E>B} = 4.9(1.7)$ for $\gamma_{inj} = \sigma(\sigma/4)$. Interestingly, we find comparable acceleration before particles encounter $E > B$ ($\Delta\bar{\gamma}_{b,E>B} = 5.6(2.7)$ for $\gamma_{inj} = \sigma(\sigma/4)$). This suggests that $E > B$ acceleration is not unique for pre-acceleration. Fig. 1a shows that most acceleration during injection occurs outside $E > B$ regions. Having a lower upstream temperature makes the $E > B$ regions contribute slightly more but does not change our main conclusion. We evolve a test-particle component that does not see the electric field in $E > B$ regions, and find 88.5%(96.3%) particles are still injected compare to self-consistent particles for $\gamma_{\rm inj} = \sigma(\sigma/4)$. No major difference exists between spectra of the test-particles and self-consistent particles (Fig. 1b). In contrast, when particle energies are reset to an energy of $10kT$ during $E > B$ crossings (resembling S22), injection is suppressed. This difference is because resetting particle energy removes the acceleration before and between $E > B$ crossings.

We demonstrated that the apparent correlation between particle injection and $E > B$ crossings do *not* have direct physical relation. Most injection is *not* achieved by $E > B$ regions. We have reached the same conclusion for different upstream temperature, σ and domain sizes, and will report elsewhere.

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* guofan@lanl.gov

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