Multifluid model of one-dimensional force-free current sheet equilibrium

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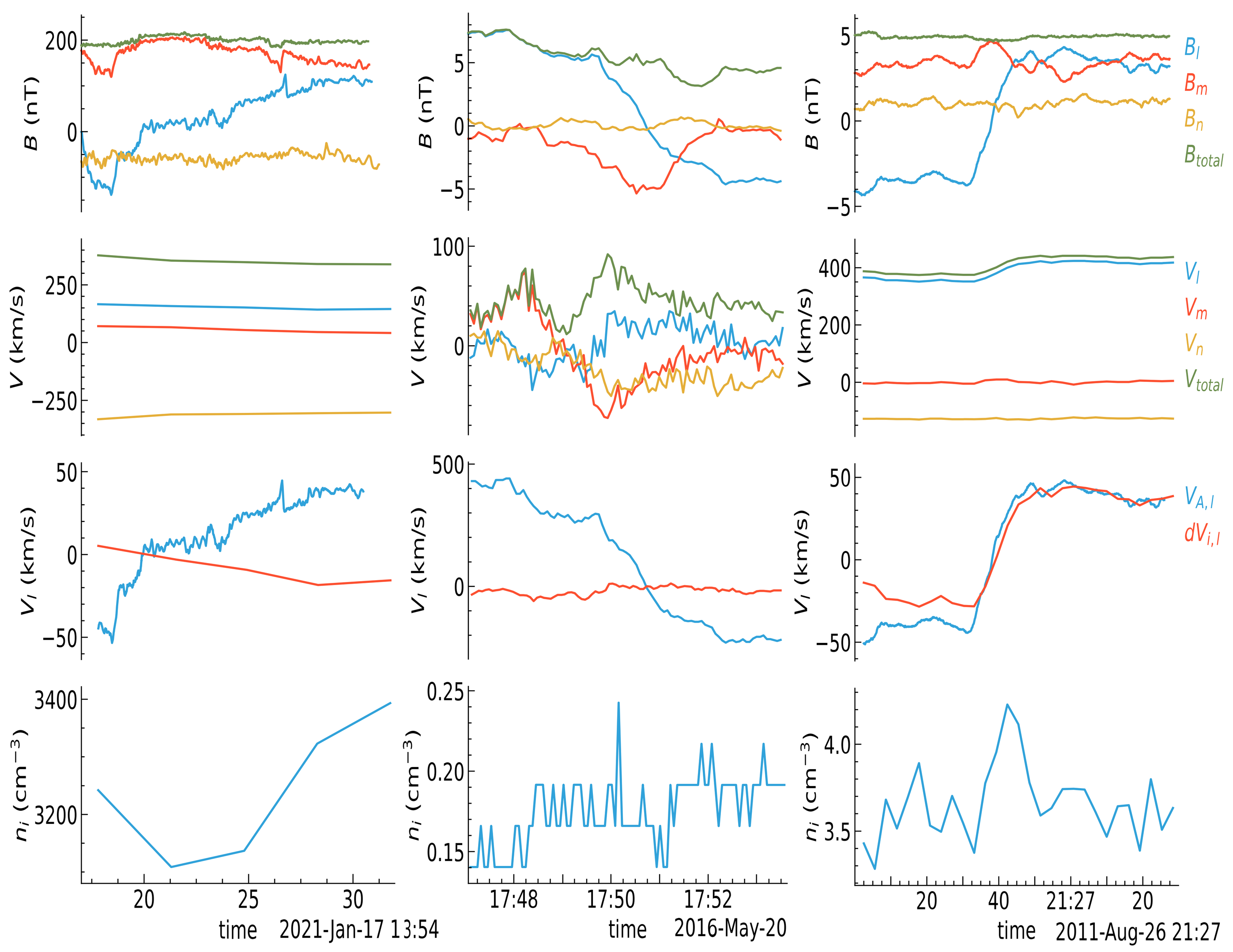
Introduction & Motivation

Solar wind discontinuities are characterized by intense, large-amplitude current sheets that exhibit complex kinetic properties beyond classical MHD models. While these discontinuities show Alfvénic properties with correlated plasma and magnetic field variations, spacecraft observations reveal that plasma velocity jumps are often significantly smaller than Alfvén velocity jumps. This discrepancy cannot be explained by plasma pressure anisotropy alone, suggesting the need for kinetic mechanisms in describing the stress balance within discontinuities.



Three examples of current sheets observed by Parker Solar Probe (PSP), ARTEMIS and Wind spacecraft with sub-Alfvenic flow velocity.

We developed a multi-fluid model for 1-D quasineutral force-free current sheet equilibria

Our model explains the sub-Alfvénic velocity jumps observed in solar wind discontinuities through the interaction of interpenetrating ion beams

$$B_x(z) = B_0 \sin\left(\frac{\kappa L}{d_i}\tan^{-1}\left(\frac{z}{L}\right)\right)$$

$$B_y(z) = B_0 \cos\left(\frac{\kappa L}{d_i}\tan^{-1}\left(\frac{z}{L}\right)\right)$$

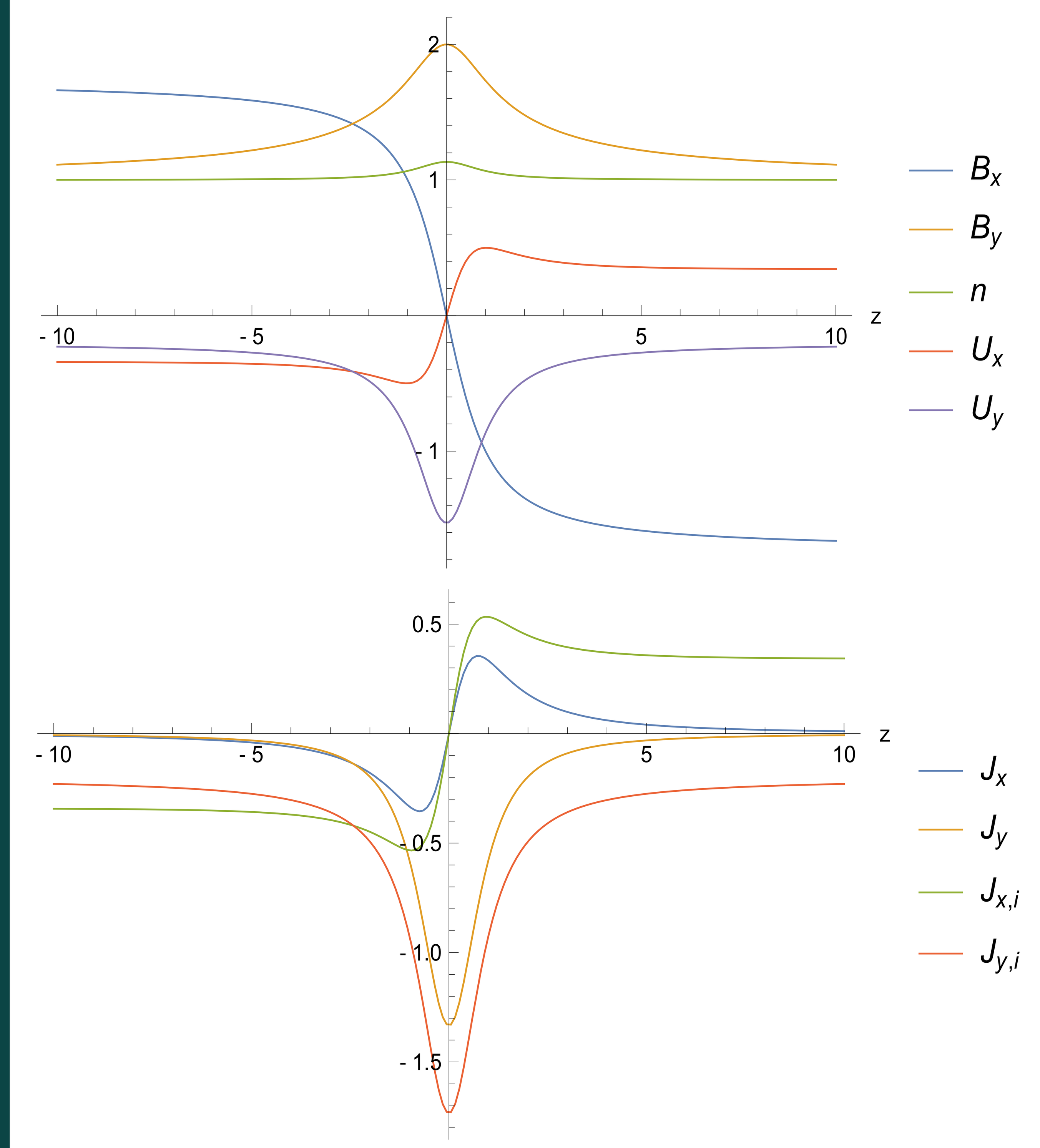
$$n(z) = n_\infty + \frac{\kappa}{V_A}\frac{\sum_\alpha \Gamma_\alpha}{1+(z/L)^2}$$

$$J_x(z) = \frac{\kappa B_0}{\mu_0 d_i}\frac{1}{1+(z/L)^2}\sin\left(\frac{\kappa L}{d_i}\tan^{-1}\left(\frac{z}{L}\right)\right)$$

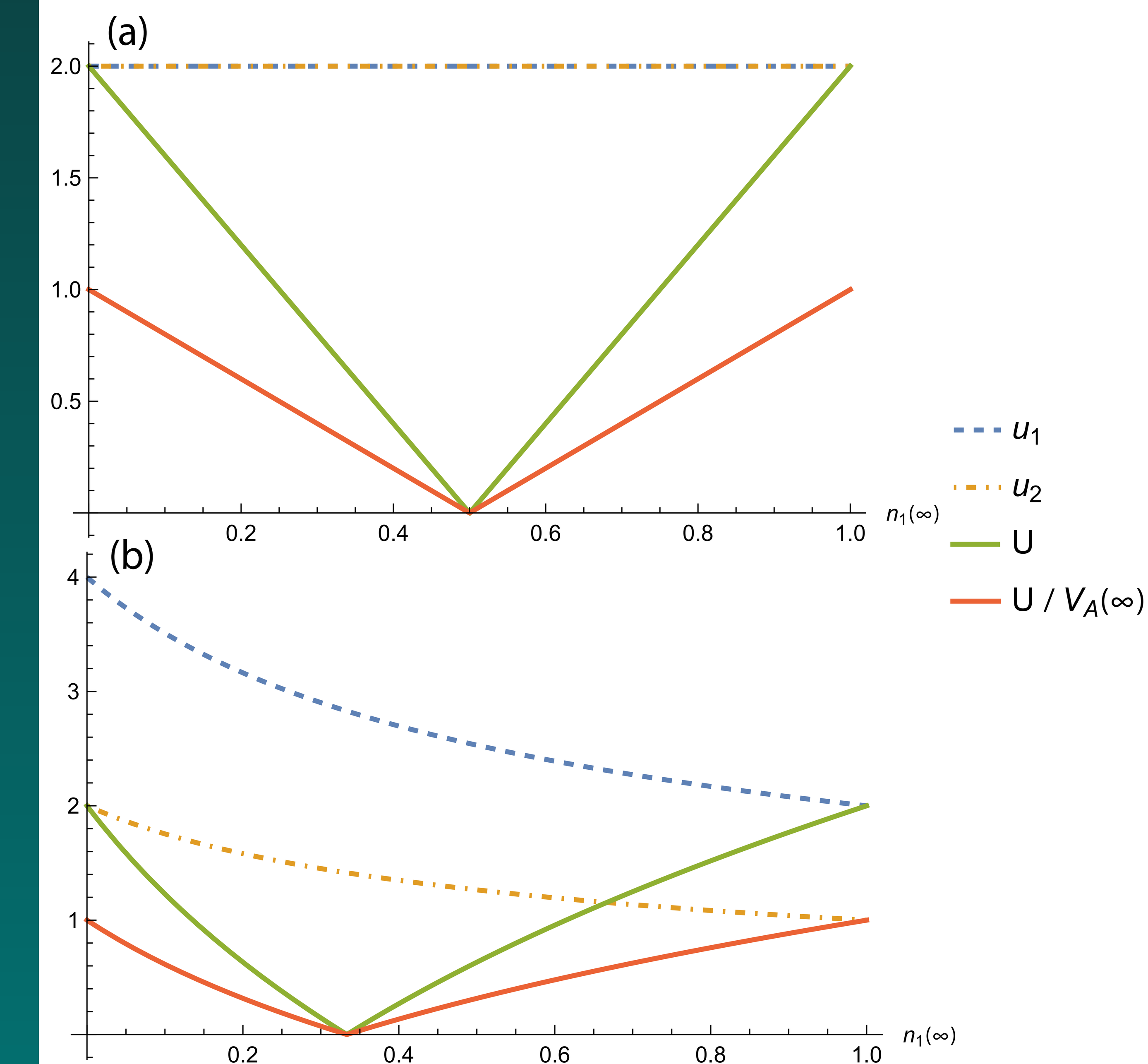
$$J_y(z) = \frac{\kappa B_0}{\mu_0 d_i}\frac{1}{1+(z/L)^2}\cos\left(\frac{\kappa L}{d_i}\tan^{-1}\left(\frac{z}{L}\right)\right)$$

where B_0: asymptotic field magnitude, n_∞: asymptotic density, V_A: Alfvén speed, κ: density enhancement factor, L: current sheet width, $d_i = c/\omega_{pi}$: ion inertial length, Γ_α: species mass flux

Results



Asymmetric case: Profiles for two ion species with same bulk velocity but different densities ($n_1(\infty) = 0.6$) and $B_y(z=\infty) = 1/2 B_0$.



Velocity ratios analysis: (a) Symmetric case with $u_{1,z} = -u_{2,z}$ showing zero normalized velocity at $n_1(\infty) = 0.5$. (b) Asymmetric case with $u_{1,z} = -2u_{2,z}$ showing zero normalized velocity at $n_1(\infty) = 1/3$, demonstrating how ion population asymmetries affect the bulk flow characteristics.