Kinetic models of current sheets in the solar wind*

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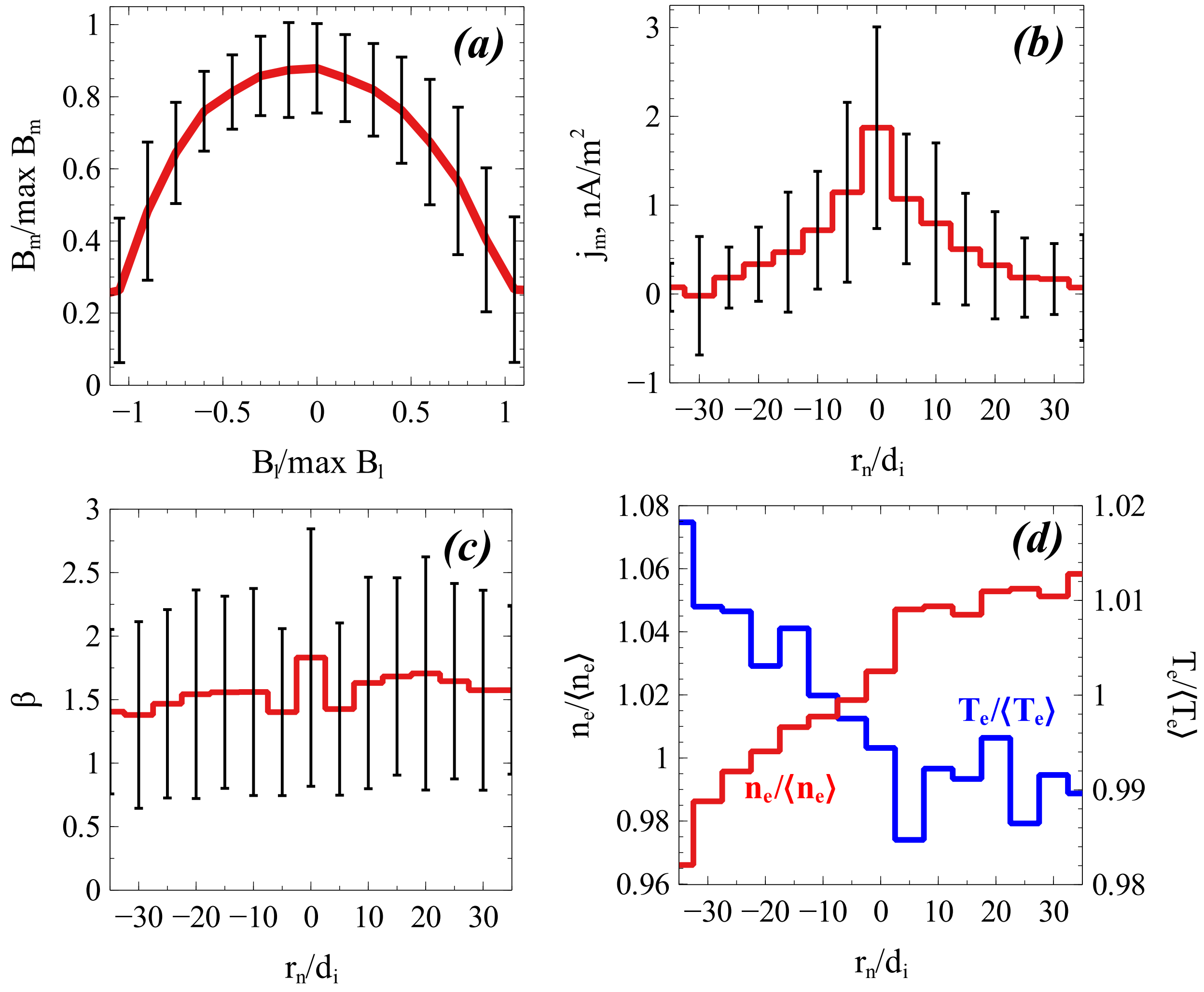
(* see ApJ 891, 86, 2020)

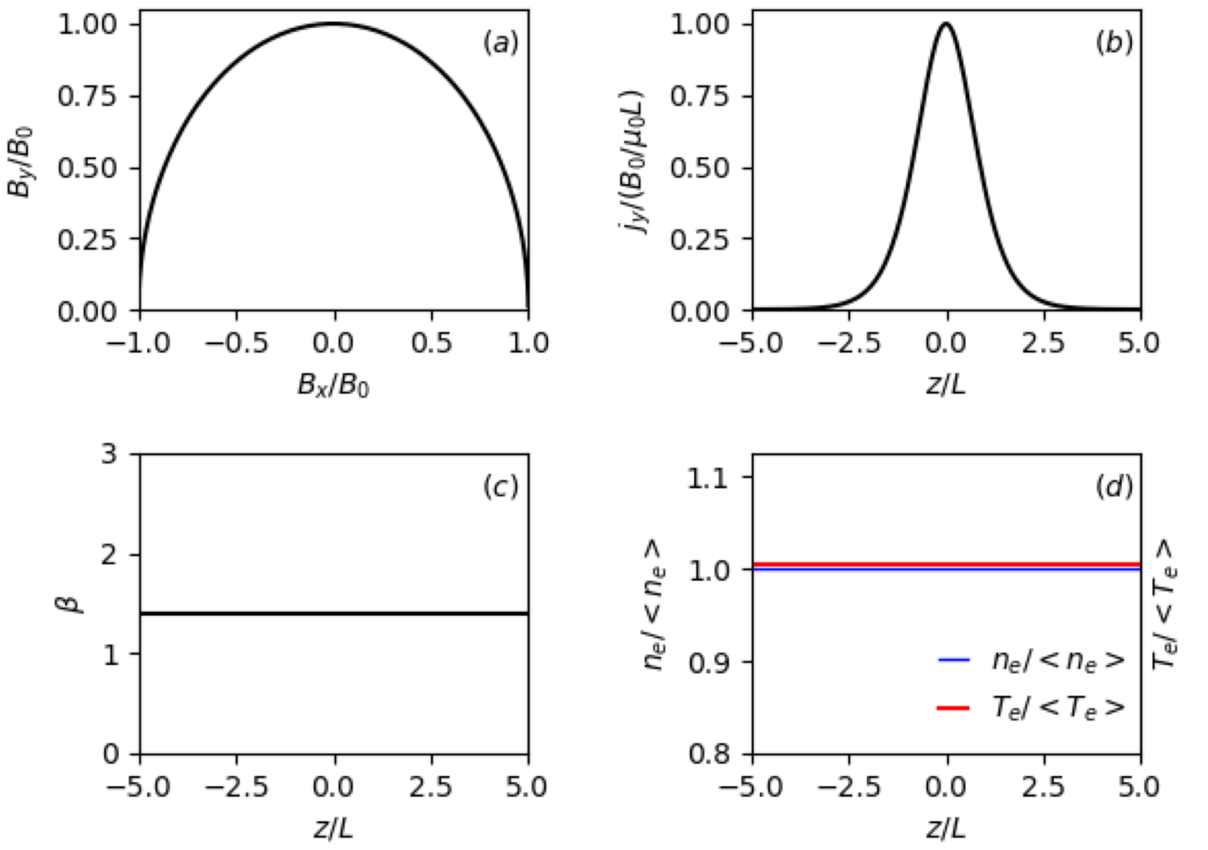
Observations



- Analysis of ARTEMIS observations of current sheets/discontinuities in the solar wind at about 1 AU found (Artemyev et al., 2018, 2019a, 2019b):
- Kinetic length scale (~ a few ion skin depths)
- Current sheet B-field and plasma-β consistent with approximately force-free configuration
- Systematic, anti-correlated, asymmetric variations of particle density and temperature across the current sheet

Can one find theoretical kinetic models for current sheets with these properties?

Kinetic equilibria with similar properties?



- First attempt: Start with force-free kinetic current sheet equilibria based on DF by Harrison & TN, 2009 (see below)
- Leads to a Harris-sheet like force-free field (with a non-constant guide field) with features similar to the observed features
- Constant plasma-β
- Problem: particle density and temperature are also constant

$$f_s = \frac{n_{0,s}}{\sqrt{2\pi v_{th,s}^2}} \mathrm{e}^{-\beta_s H_s} \left[\mathrm{e}^{\beta_s u_{ys} p_{ys}} + a_s \cos(\beta_s u_{xs} p_{xs}) + b_s \right]$$

(H_s, p_{xs}, p_{ys} = constants of motion)

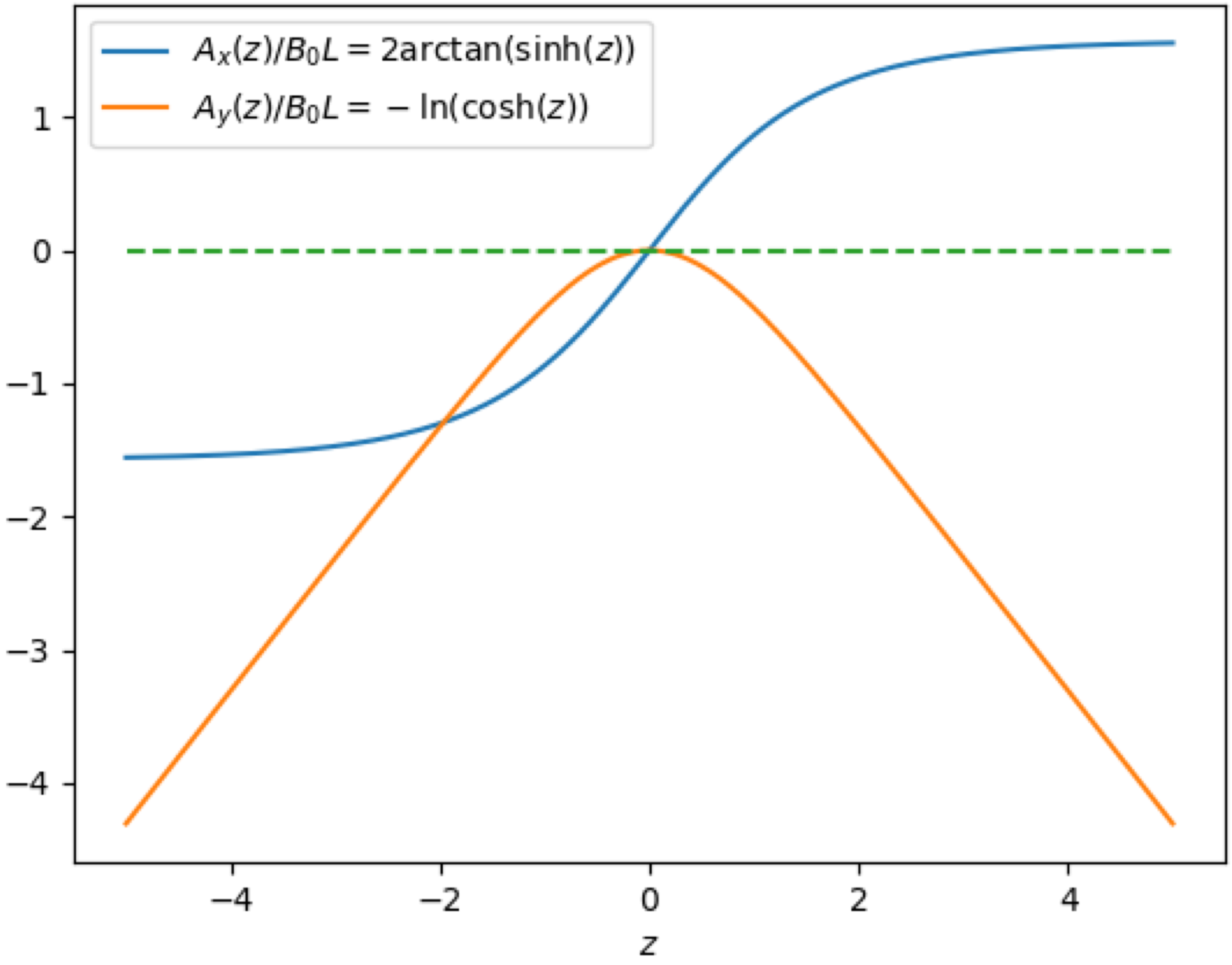
(Asymmetric) Gradients in n and T?

- Want to add gradients in n and T
- But want to keep current sheet force-free
- Density n and pressure P_{zz} are functions of A_x, A_y (and ϕ)
- Moments of

$$f_s(z, \mathbf{v}) = F_s(H_s, p_{xs}, p_{ys})$$

$$p_{xs} = m_s v_x + q_s A_x(z)$$
$$p_{ys} = m_s v_y + q_s A_y(z)$$

- Can we add additional terms to the DF to get the desired form for n and T?



- Need asymmetric/odd density profile in z
- A_y even → need dependence on A_x that is odd as well
- Additional DF terms need to be odd functions of p_x
- However, no contribution to j_x wanted!

Additional term in DFs

$$F_{s,total} = F_{s,ff} + \Delta F_s$$

$F_{s,ff}$: any force-free distribution function

ΔF_s: the additional term, e.g. $\Delta F_s \propto K_s(p_{x,s})G_s(H_s)$

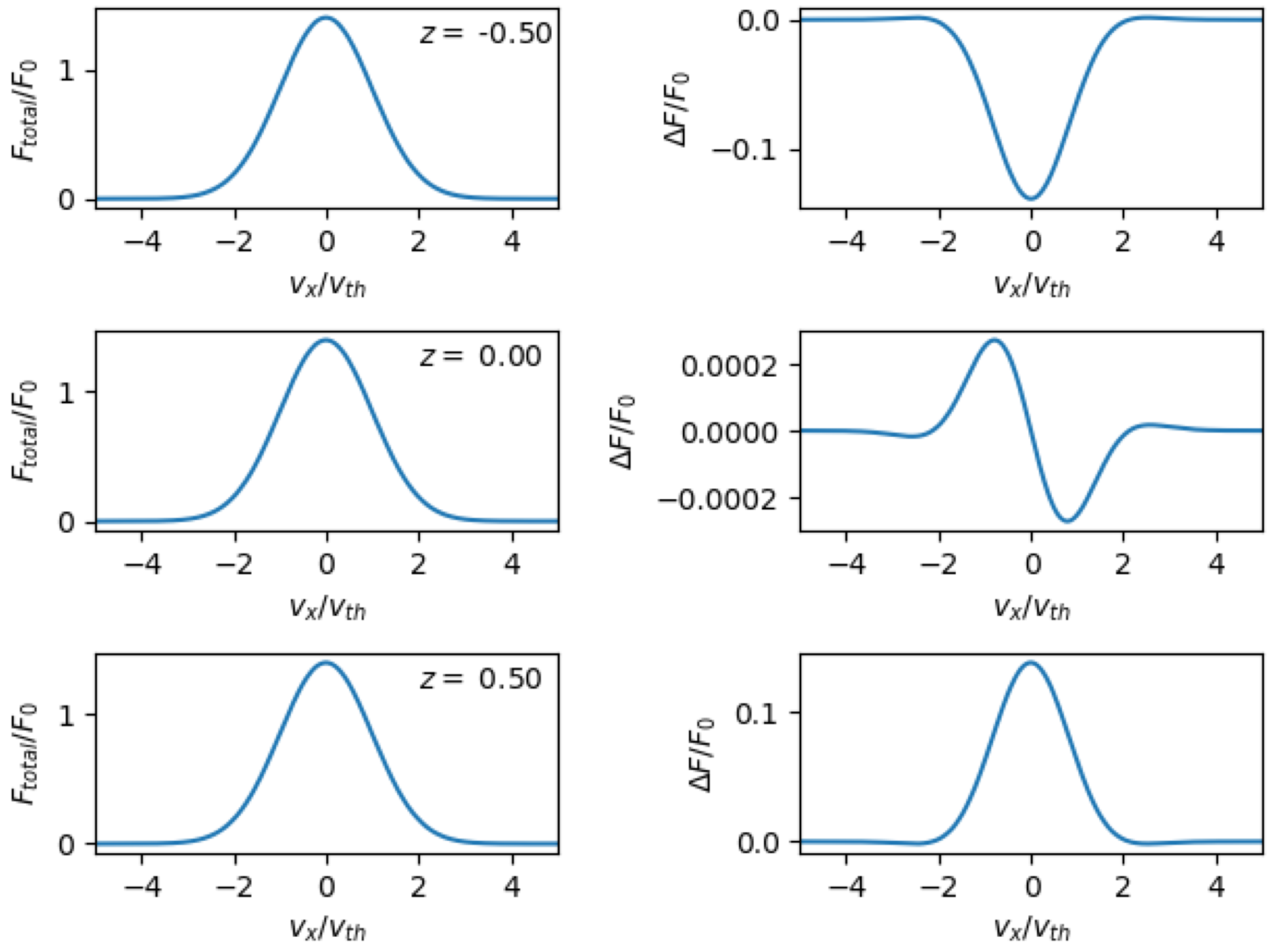
Conditions: $\int K_s(p_{x,s})G_s(H_s)d^3v \neq 0, \quad \int v_x K_s(p_{x,s})G_s(H_s)d^3v$

Example: $K_s(p_{x,s}) \propto p_{x,s},$

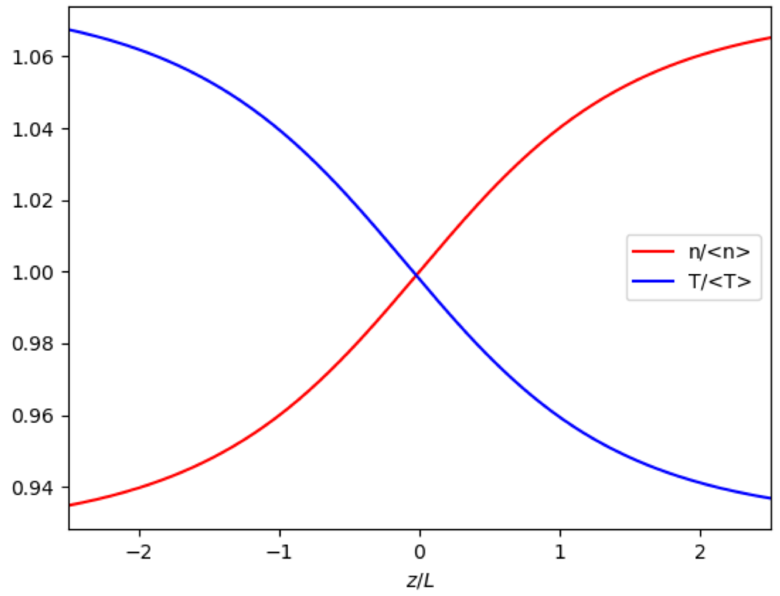
$$G_s(H_s) \propto \exp(-H_s/k_BT_{s,1}) - a_s \exp(-H_s/k_BT_{s,2})$$

There is actually a method of finding appropriate combinations systematically.

Example



- For parameters relevant for observations



Concluding remarks

- Ad hoc method seems to work well for parameter values needed
- One has to check individually that the total DF > 0 !
- The problem becomes more complicated if one cannot arrange for ϕ = 0 (under investigation)