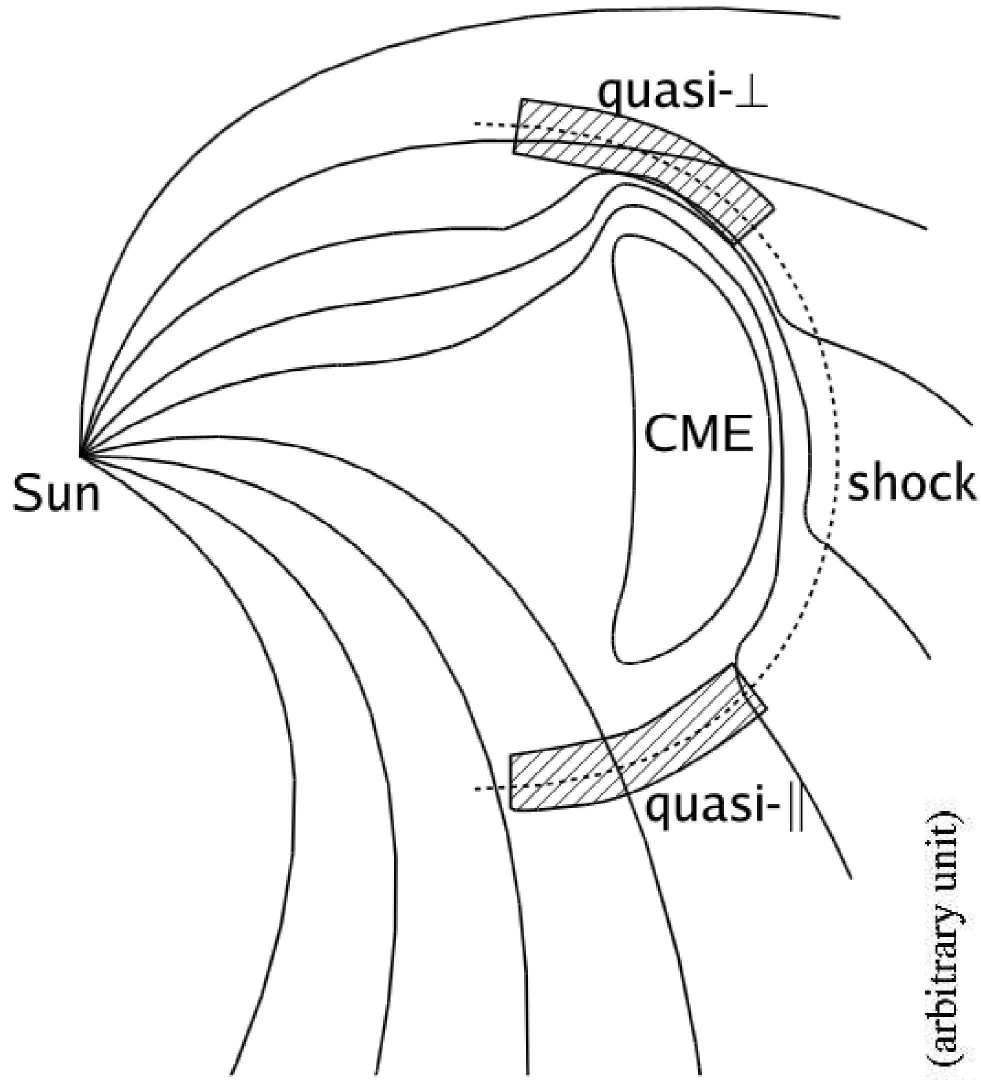
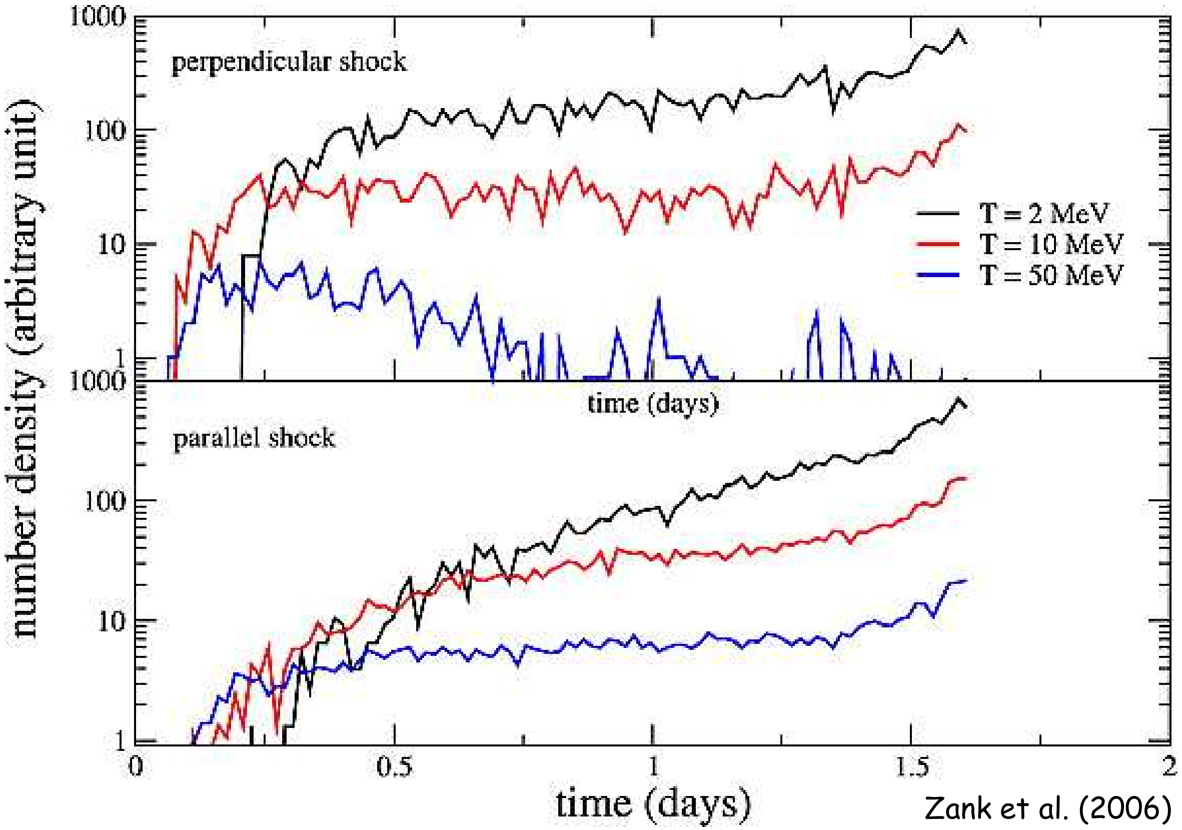
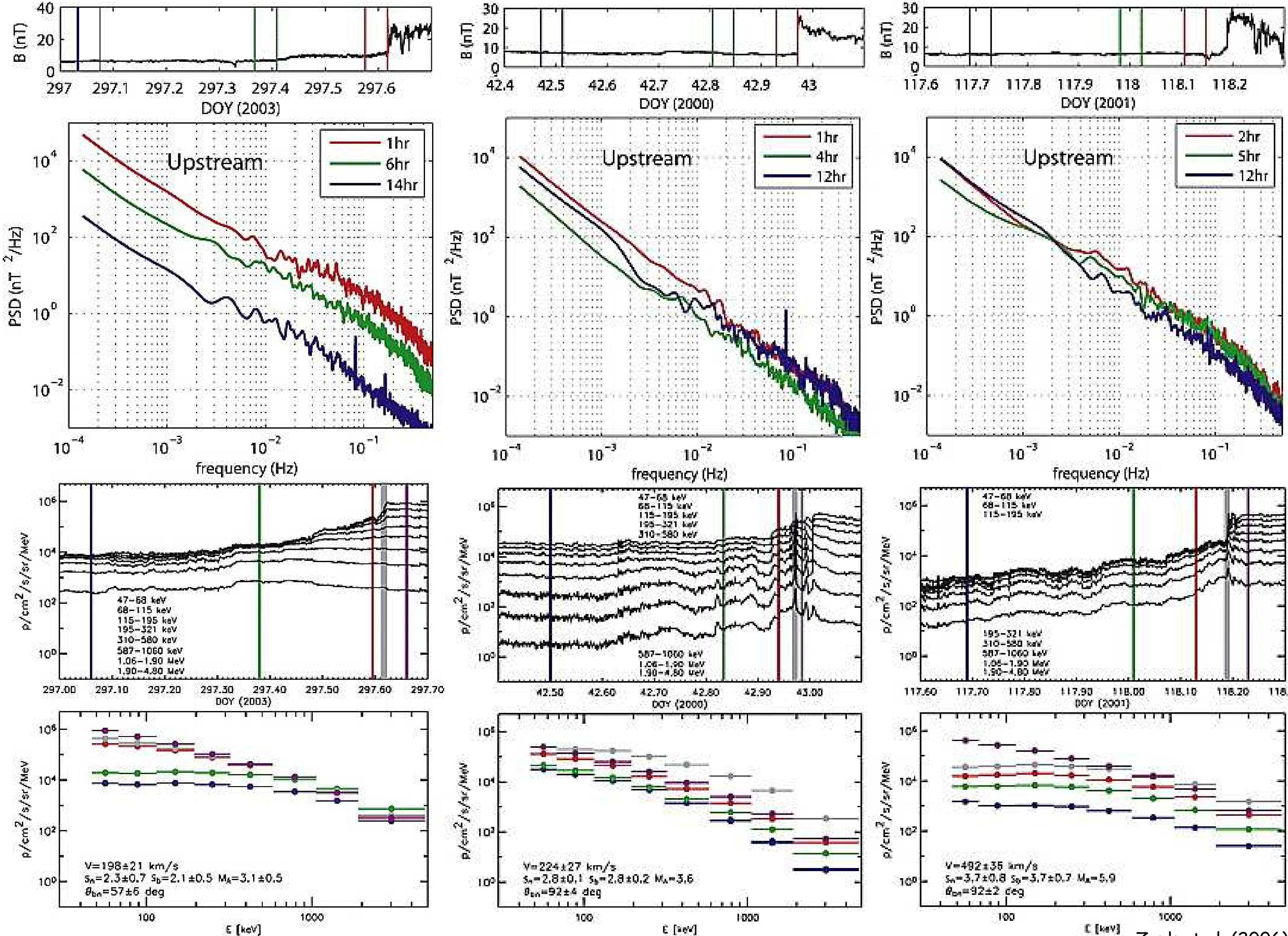


Thanks to wave excitation by the streaming instability at the parallel shock, the parallel diffusion coefficient is smaller than the diffusion coefficient at the quasi-perpendicular shock. Consequently, particle trapping is more efficient at the parallel shock, thus limiting particle escape. This is reflected in the intensity profiles, which show a very rapid rise time and formation of a plateau in the quasi-perpendicular shock case.

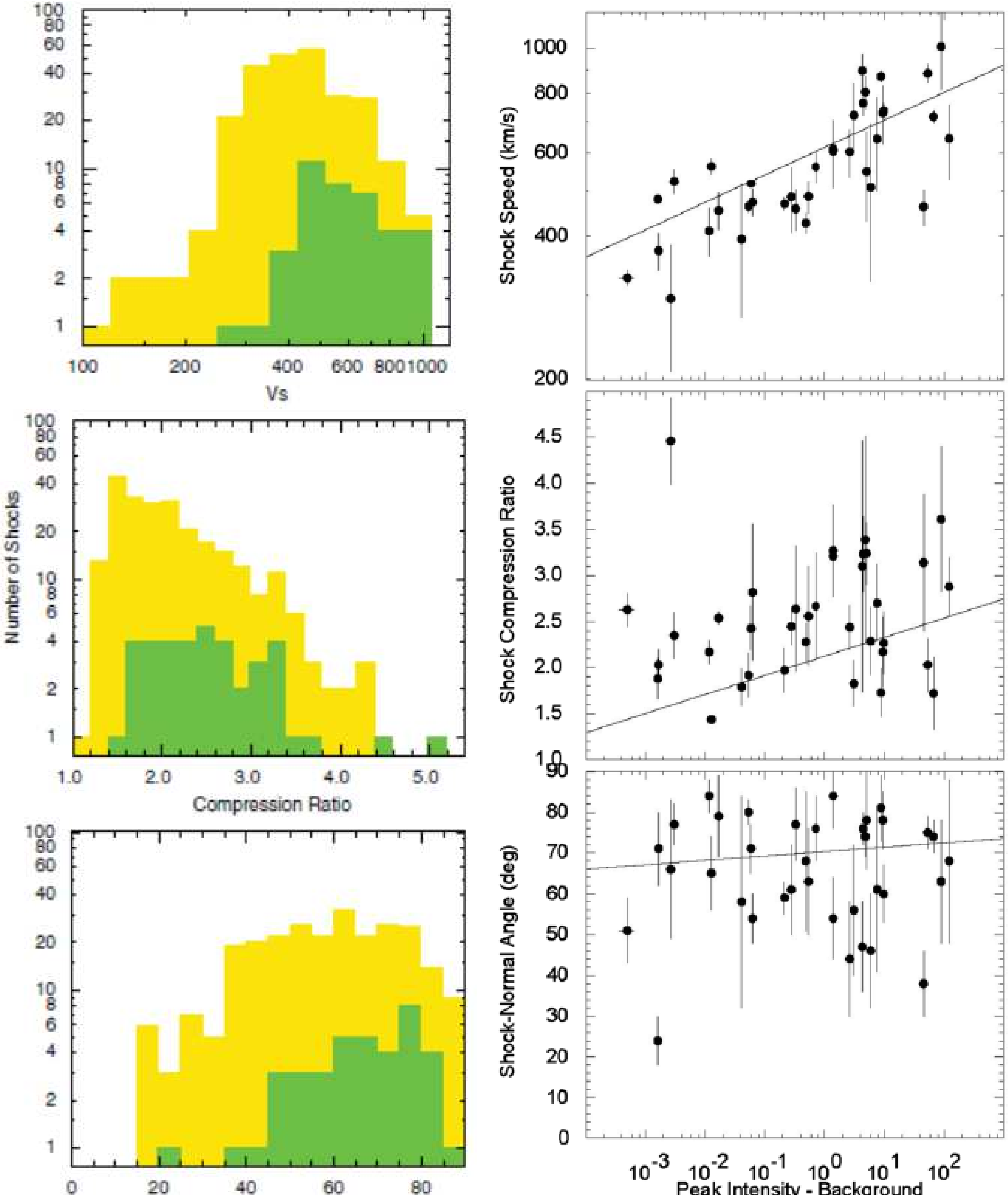


Zank et al. (2006)

Zank et al. (2006) suggested that higher proton energies are achieved at quasi-parallel rather than highly perpendicular interplanetary shocks within 1 AU.



Zank et al. (2006)



Reames (2012)

The in-situ observations by Reames (2012) show that the quasi-parallel shock waves are rarely able to produce measurable acceleration at 1 AU.

It may seem surprising that only 39 of 258 shocks at 1 AU, ~15%, have significant particle acceleration to 1–10 MeV amu^{-1}. The dearth of acceleration is explained by (1) a low shock speed, (2) a low shock compression ratio, and (3) a low value of the shock-normal angle with the magnetic field.

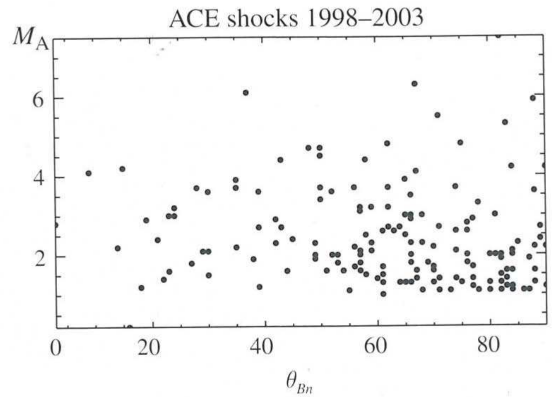
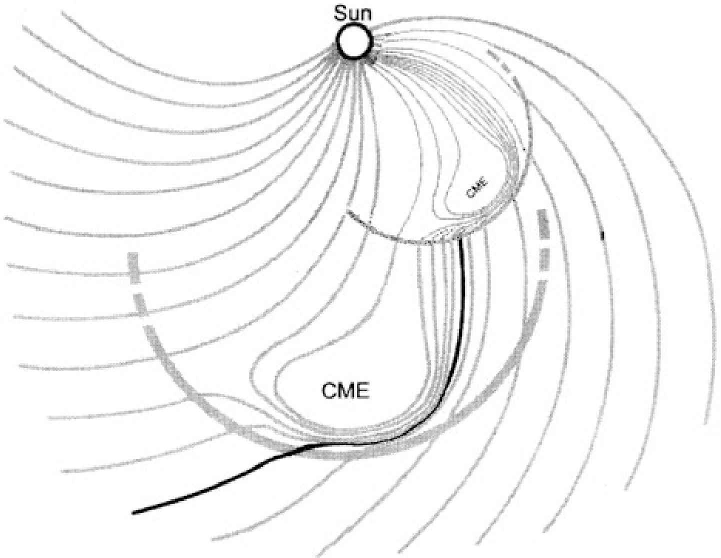


Fig. 9.10 in C. J. Schrijver and G. L. Siscoe (2010)

Twin-CME



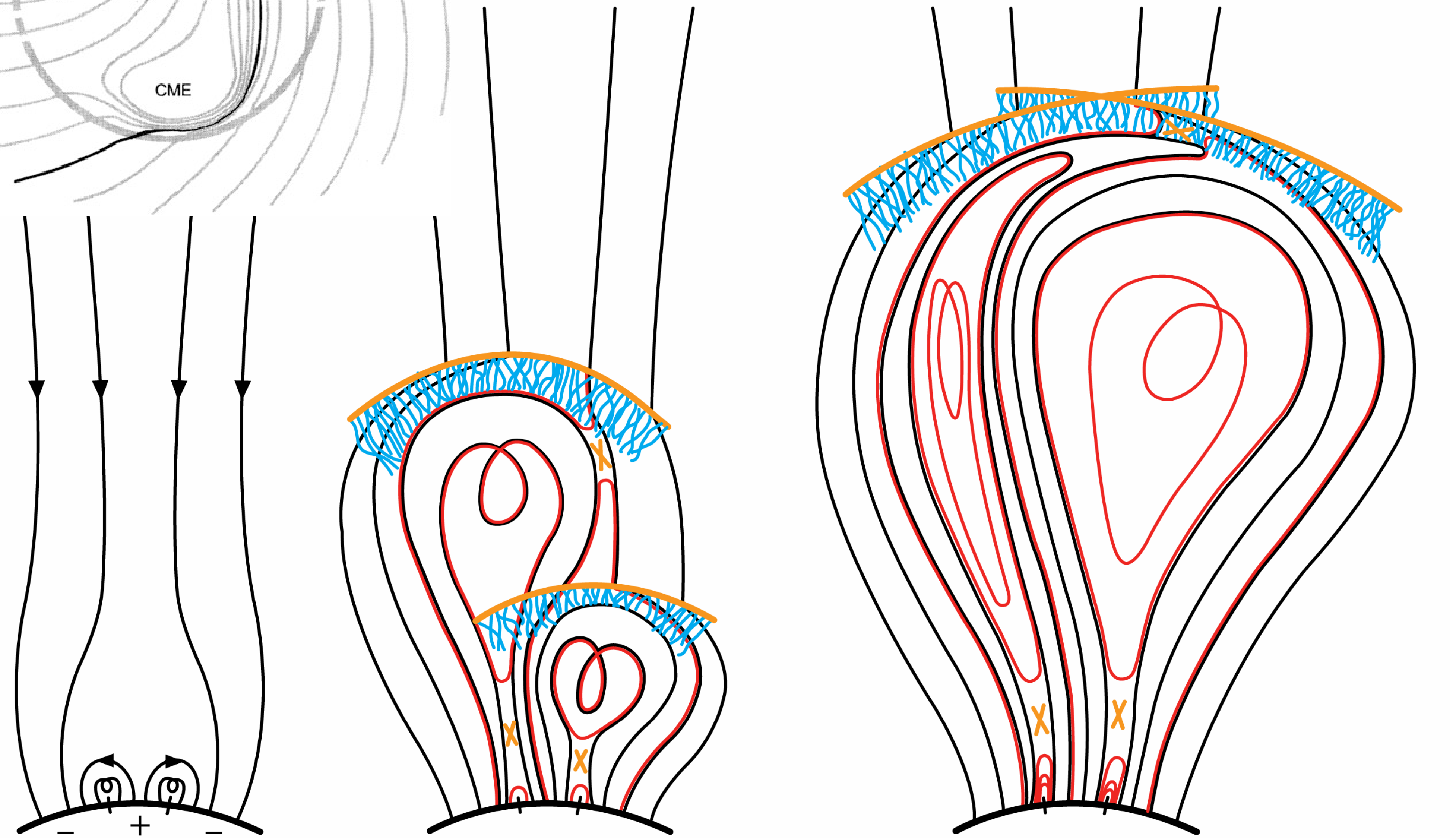
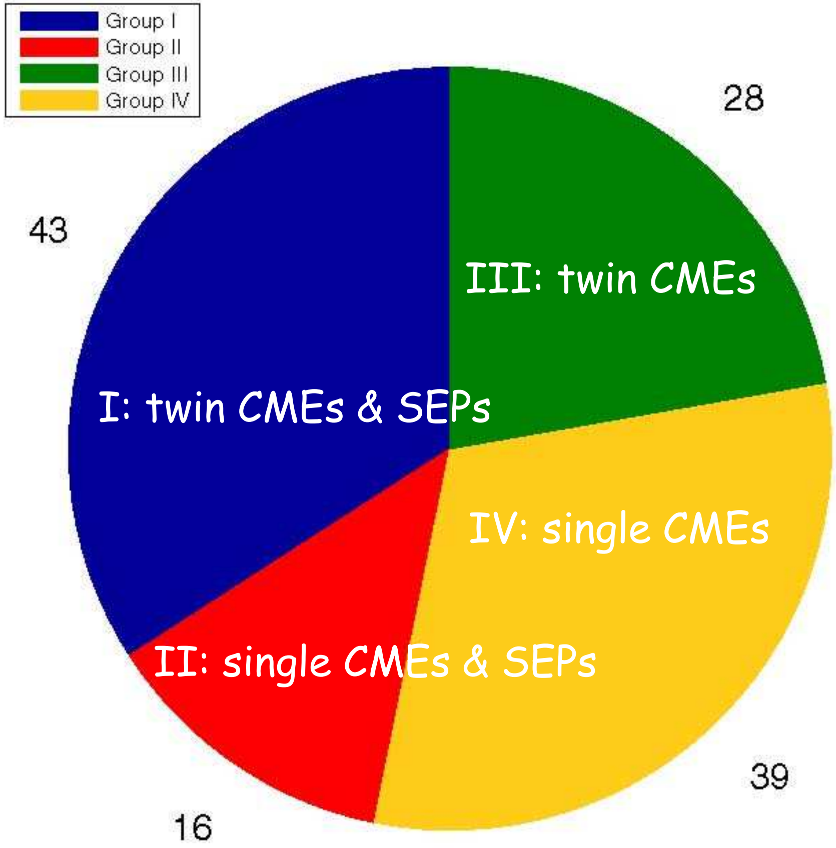
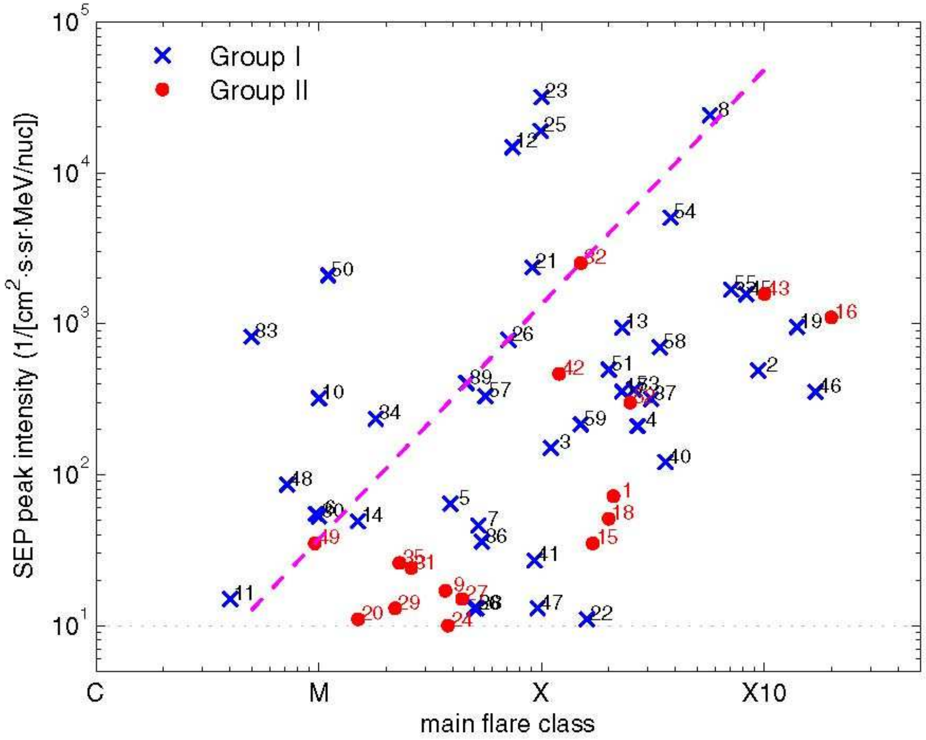


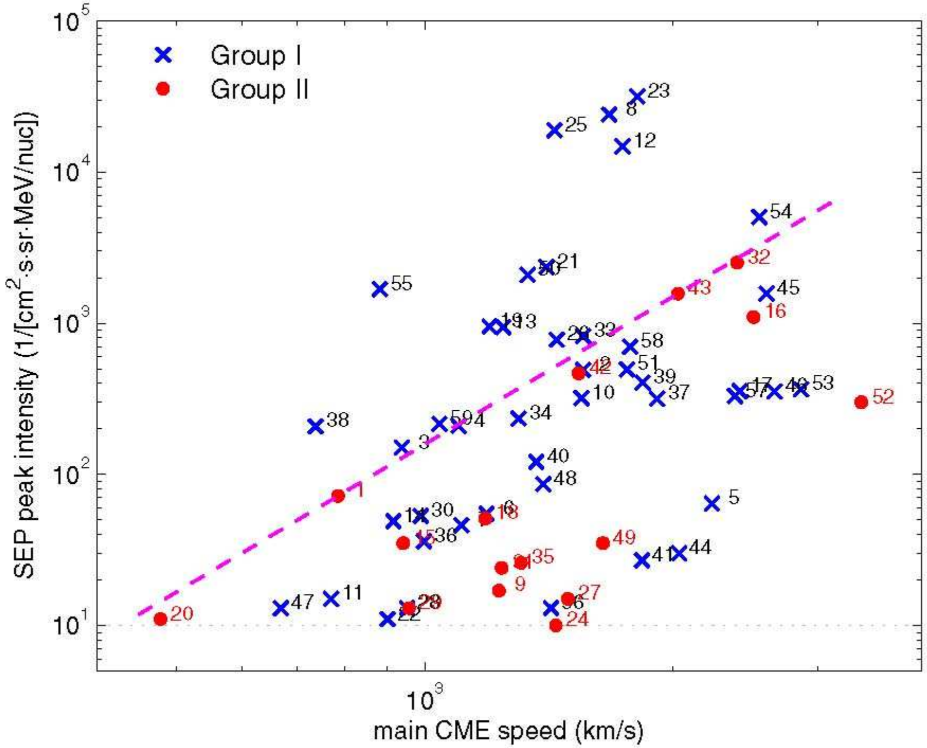
Fig. 3.12 in Donald V. Reames (2017)

Gang Li in 2014 iSWWS

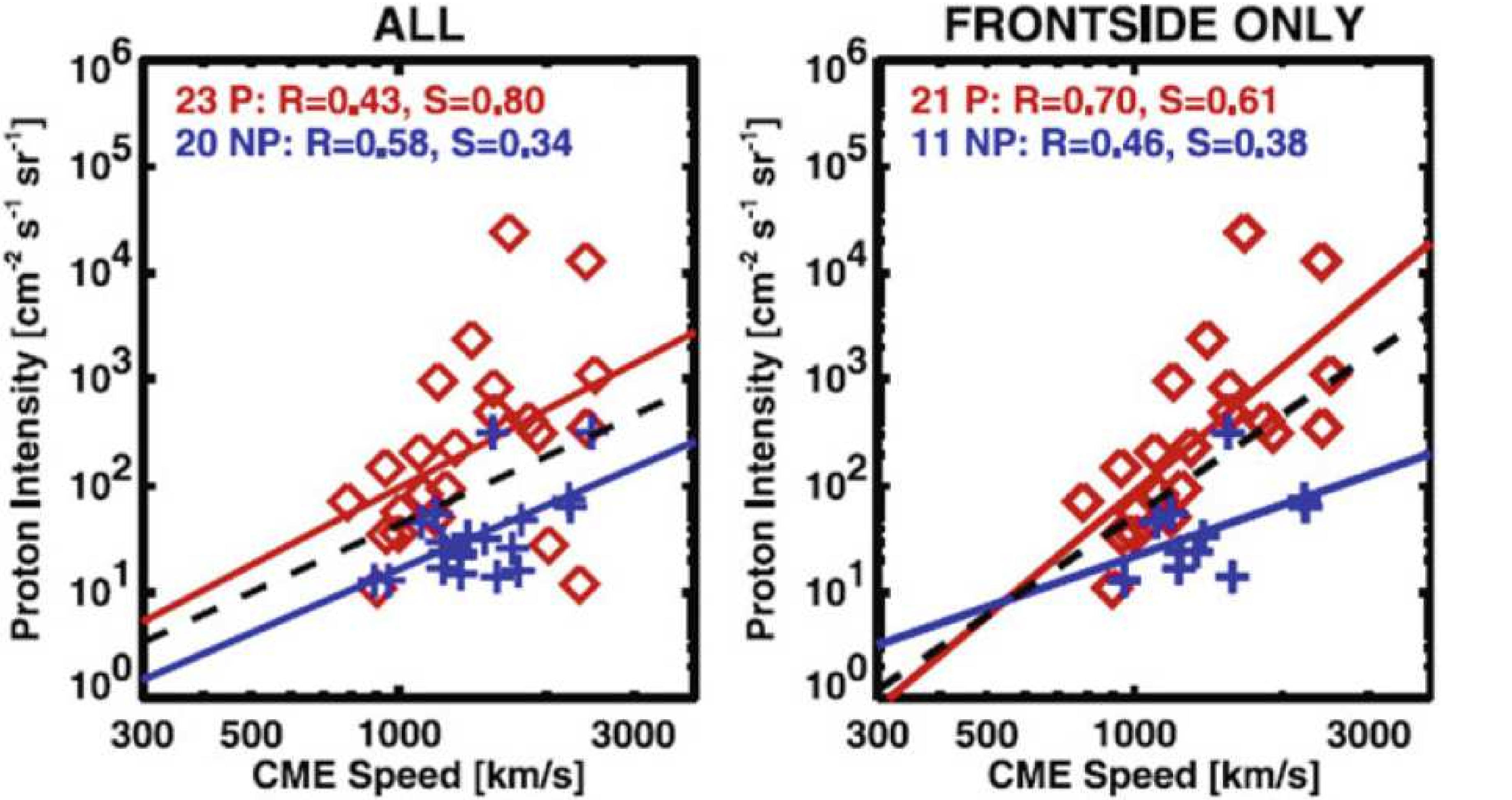




In the "twin-CME" scenario, the presence of the first CME can set up a favorable environment for efficient particle acceleration at the second CME-driven shock, therefore weakening any dependence of the peak intensity on the flare size and CME speed if there was any.



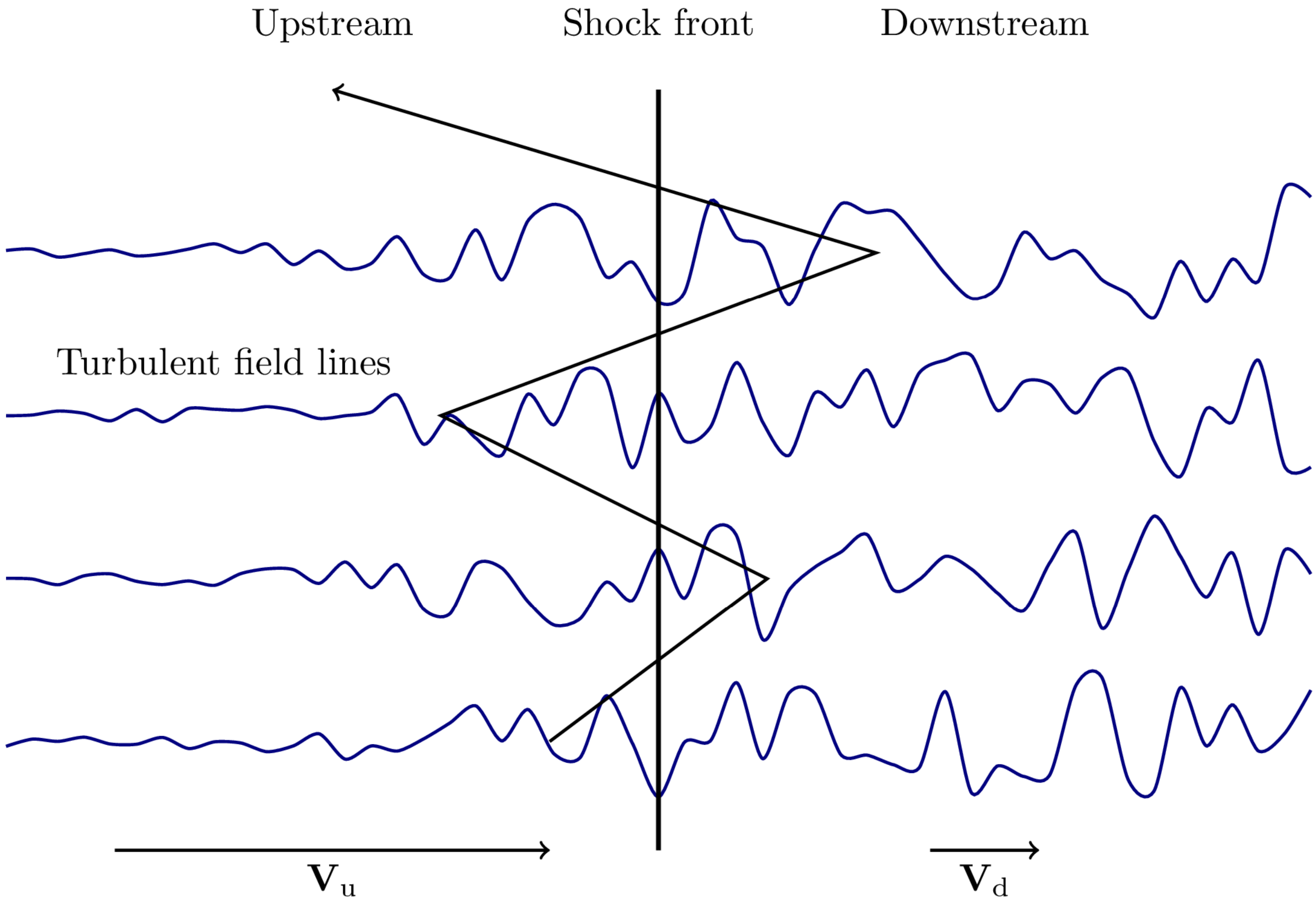
Ding et al. (2013)



The presence of preceding CMEs seemed to be the discriminating characteristic of the high- and low-intensity SEP events. Possible mechanisms of increased particle intensities were attributed to the effects related to the modification of the primary shock strength propagating in the environment of enhanced density produced by the preceding CME, effects due to changed magnetic configuration of the interplanetary magnetic field allowing particles to experience repeated acceleration, or to the existence of favorable seed particles as a consequence of the preceding CME.

Fig. 16.1 in M. P. Miralles and J. Sánchez Almeida (2011)

Diffusive Shock Acceleration (first-order Fermi acceleration)

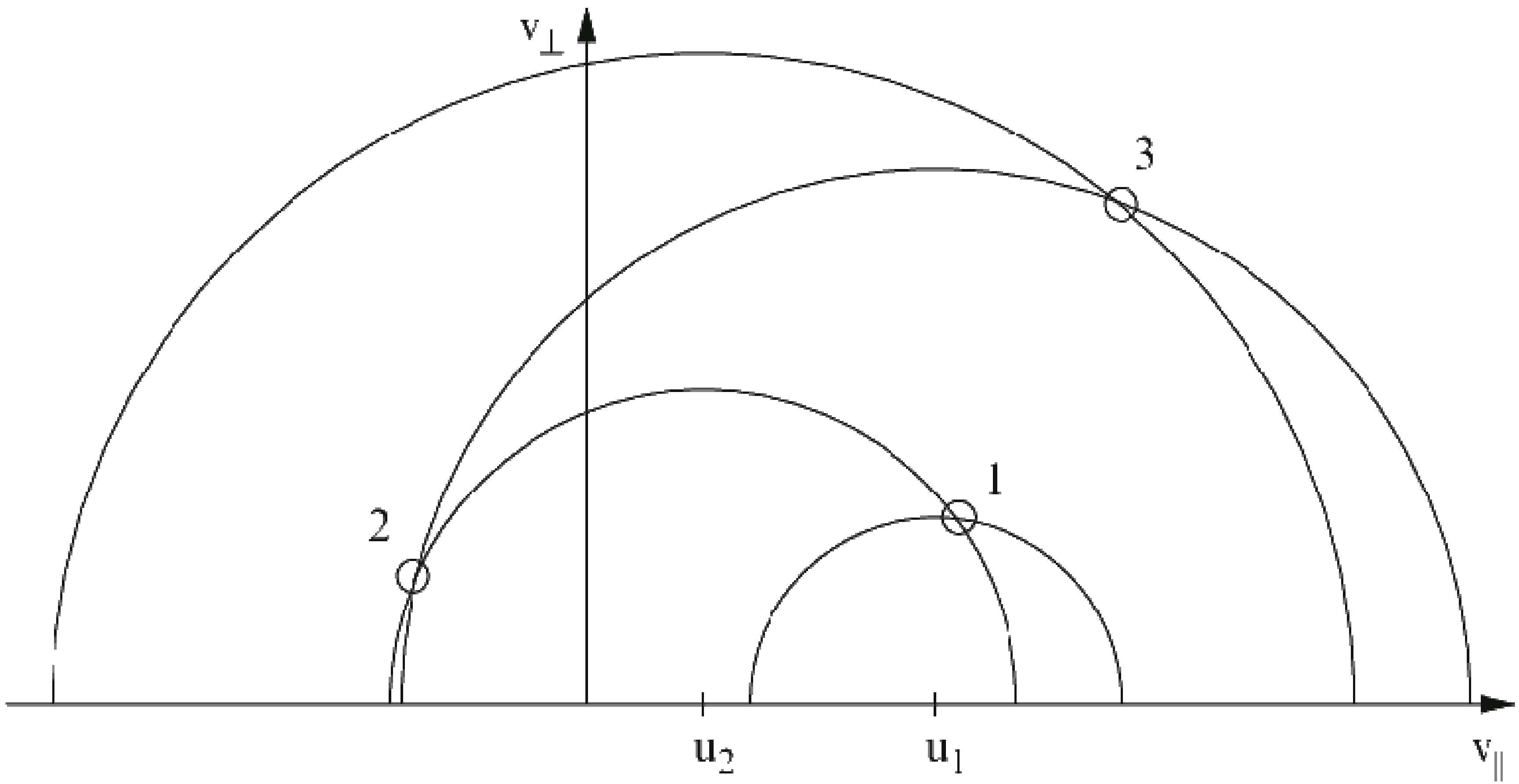


https://ay201b.wordpress.com/2013/04/09/the-acceleration-of-cosmic-rays-in-shock-fronts-bell-1978/

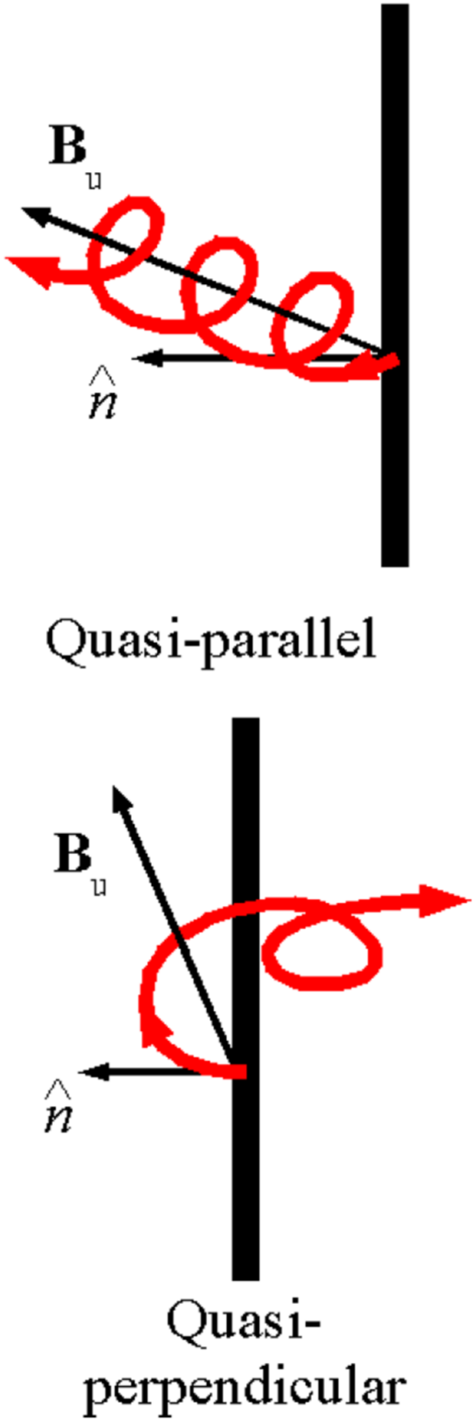
One interaction with the shock cannot provide very energetic particles → many interactions needed

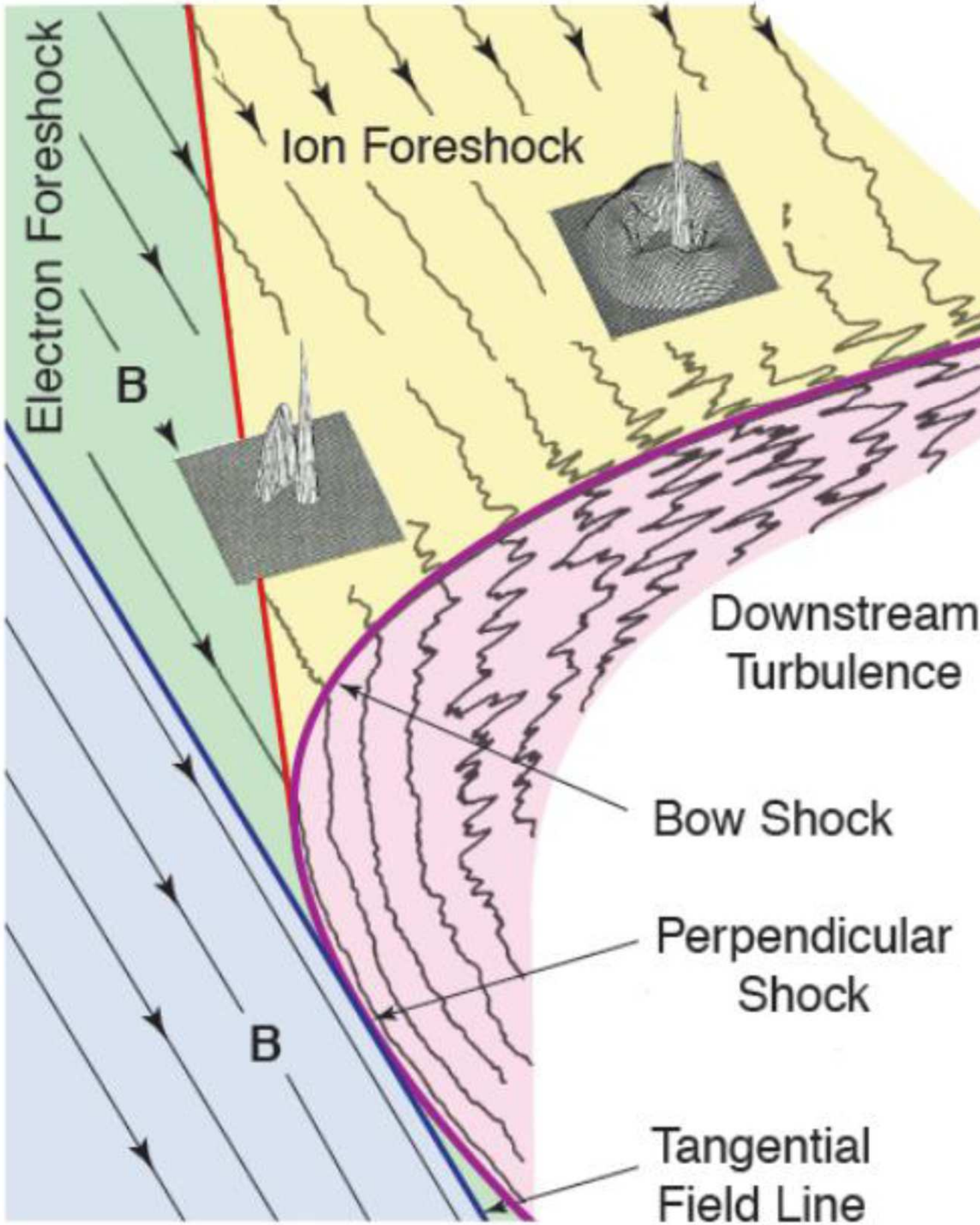
Particle scattering → particle can interact with the shock many times

Simplest to describe for quasi-parallel shock waves

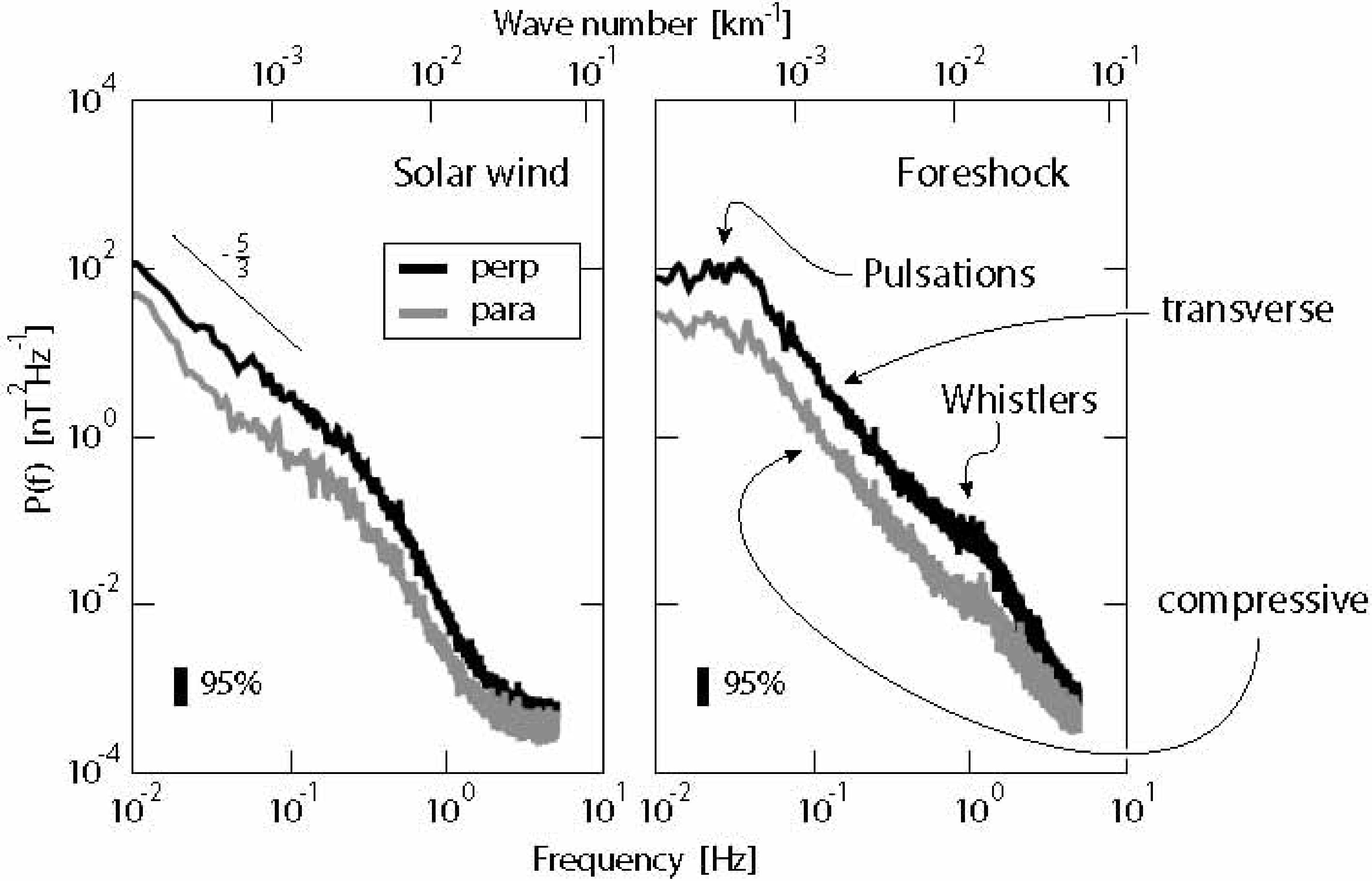


https://www.researchgate.net/figure/Diffusive-shock-acceleration-An-energetic-charged-particle-scatters-off-magnetic_fig4_322893188



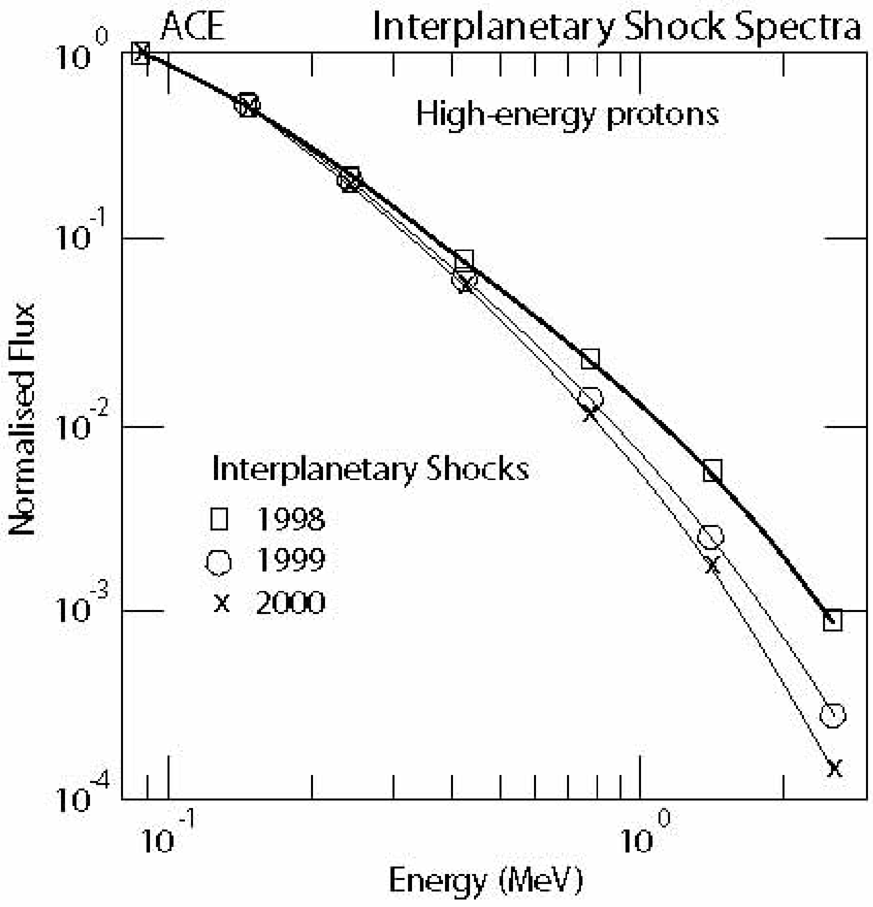


http://www.cifs-isss.org/presentazioni/2015-september/Parks_Lecture%203_Bow%20shock.pdf

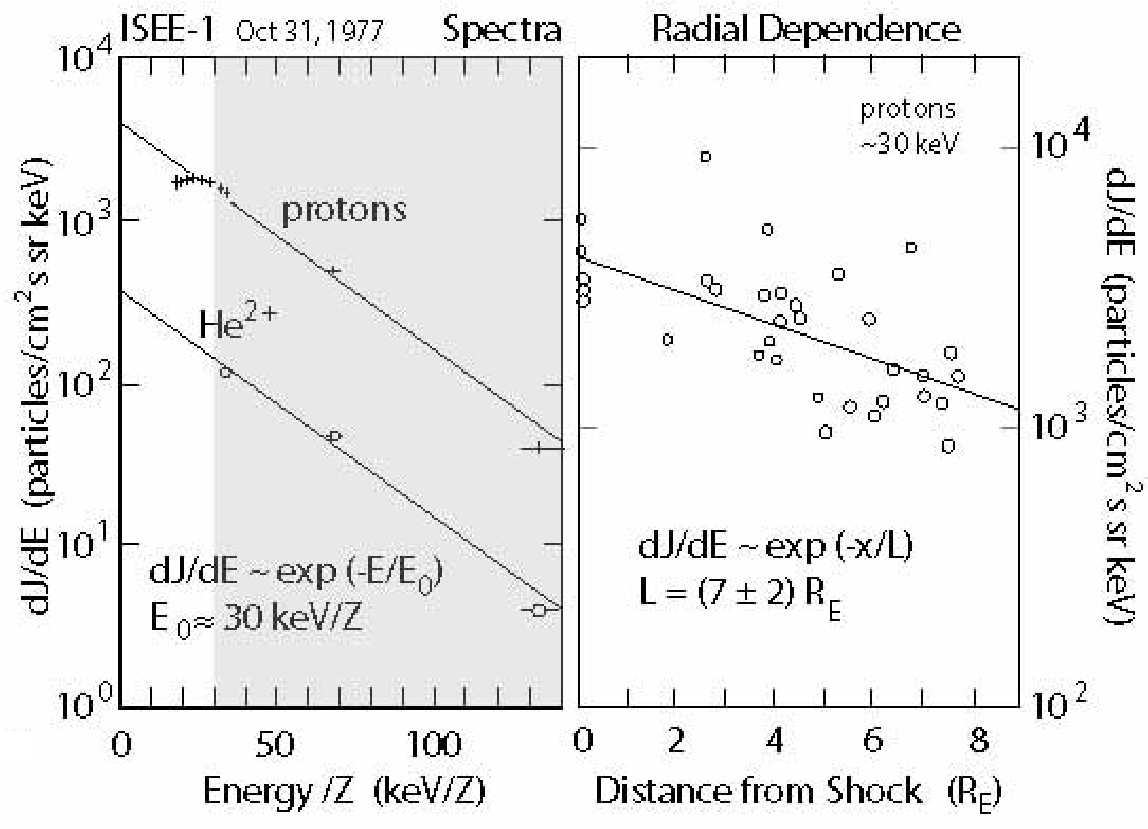


Power spectral densities for the magnetic fluctuations measured by CLUSTER in the solar wind and foreshock. In both cases the anisotropy is quite pronounced with the solar wind behaving like Kolmogorov at low frequencies/large wavelengths.

http://inspirehep.net/record/789082/files/chap6-fig-narita1.png



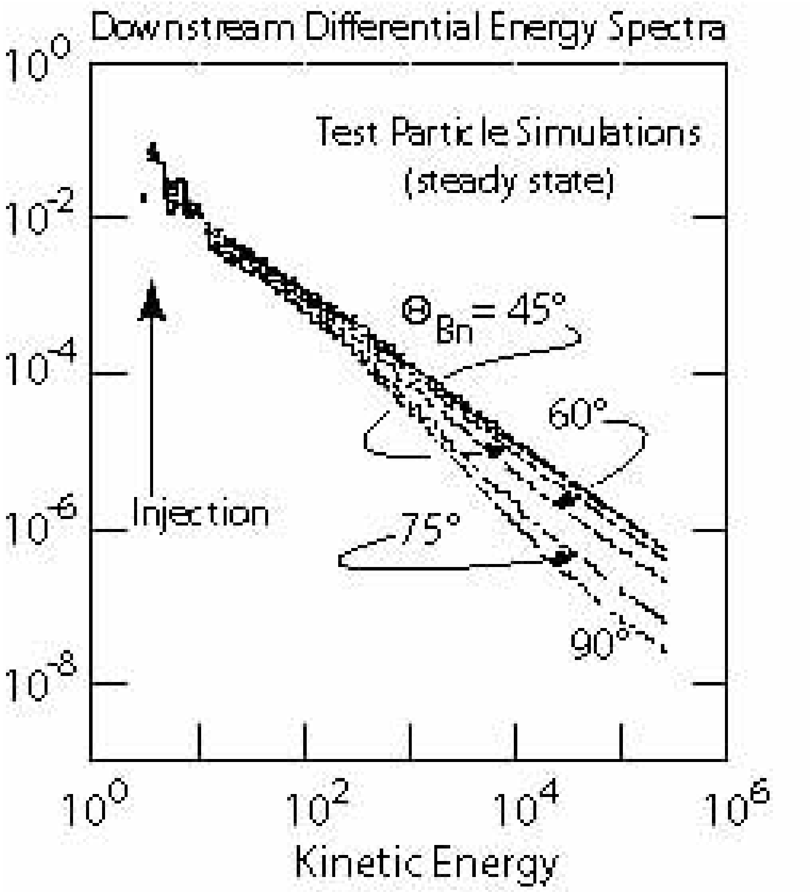
Energetic ion spectra upstream of Earth's bow shock

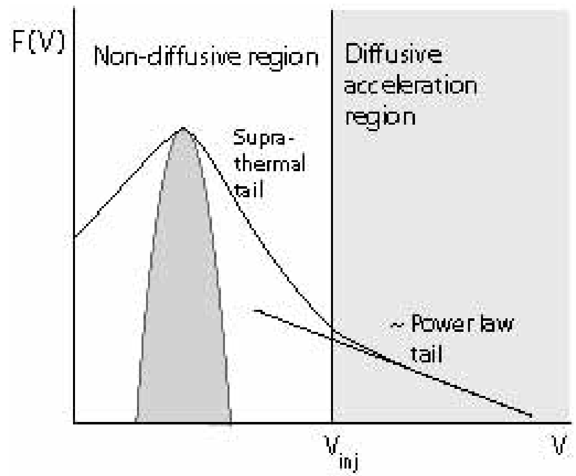


Obviously the acceleration physics is similar at bow shocks and at travelling shocks. Both kinds of shocks accelerated ions to higher energies when being exposed to scattering centres to both sides of the shock. Hence, the acceleration mechanism generating these particles is of the kind of the first-order Fermi mechanism (or diffusive acceleration). This is in contrast to the power spectra observed at higher energies in cosmic rays.

http://inspirehep.net/record/789082/files/chap6-fig-ace.png http://inspirehep.net/record/789082/files/chap6-fig-ipav.png

Test particle simulations of shock acceleration injecting protons into a pre-existing shock at different shock normal angles.





→Note that the flattest spectrum is obtained for small Θ_{Bn} in the quasi-parallel shock, but the dependence is weak.

→The difference is only in the flux with the quasi-parallel shock generated flux at given energy about one order of magnitude larger than the quasi-perpendicular shock generated flux.

→Nevertheless, time dependent test particle simulations of the same kind show that even though the fluxes are low the quasi-perpendicular shock accelerates particles to higher energy at a given time than the quasi-parallel shock.

→In other words, quasi-perpendicular shocks show a higher acceleration rate than quasi-parallel shocks.

http://inspirehep.net/record/789082/files/chap6-fig-testsim.png