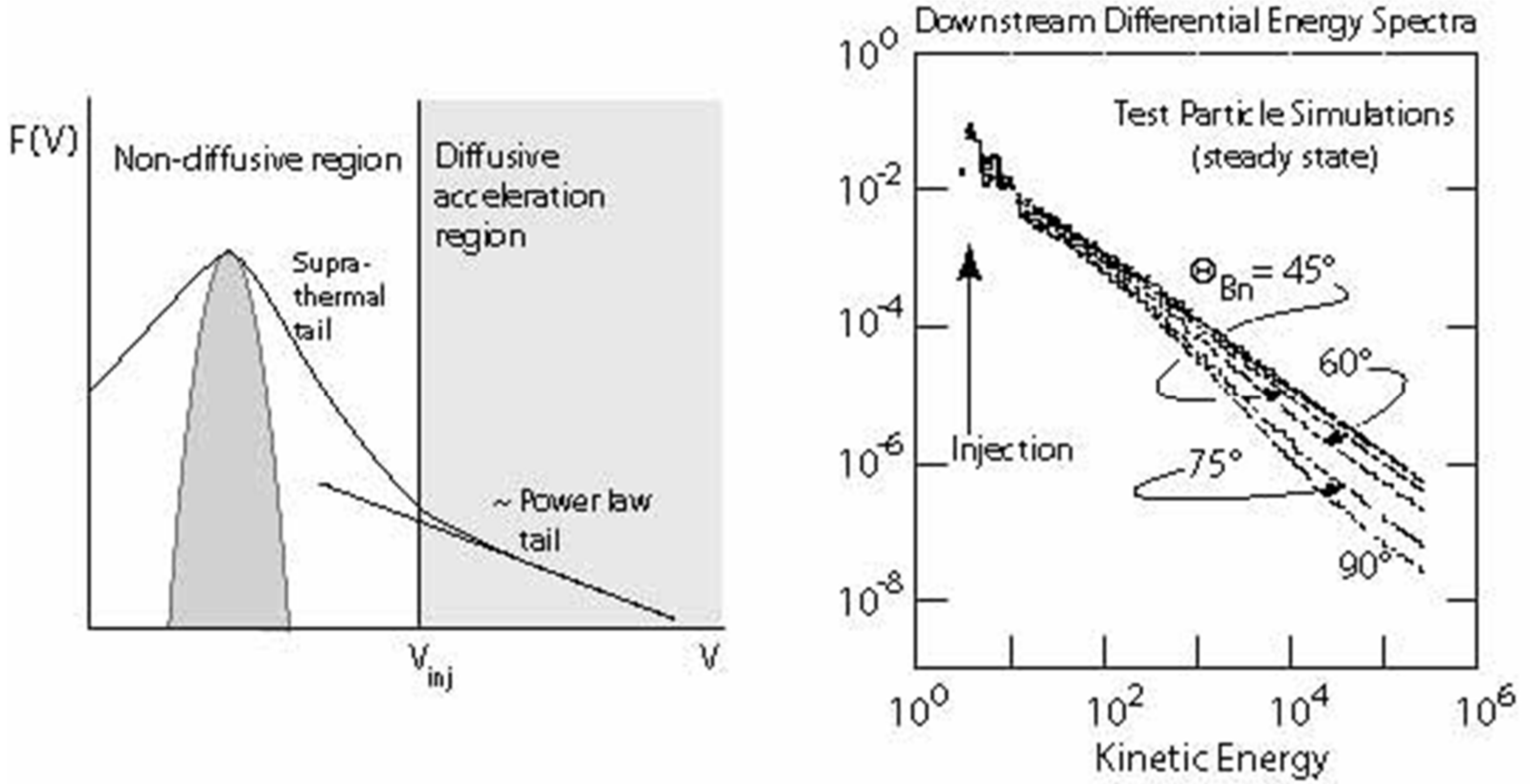
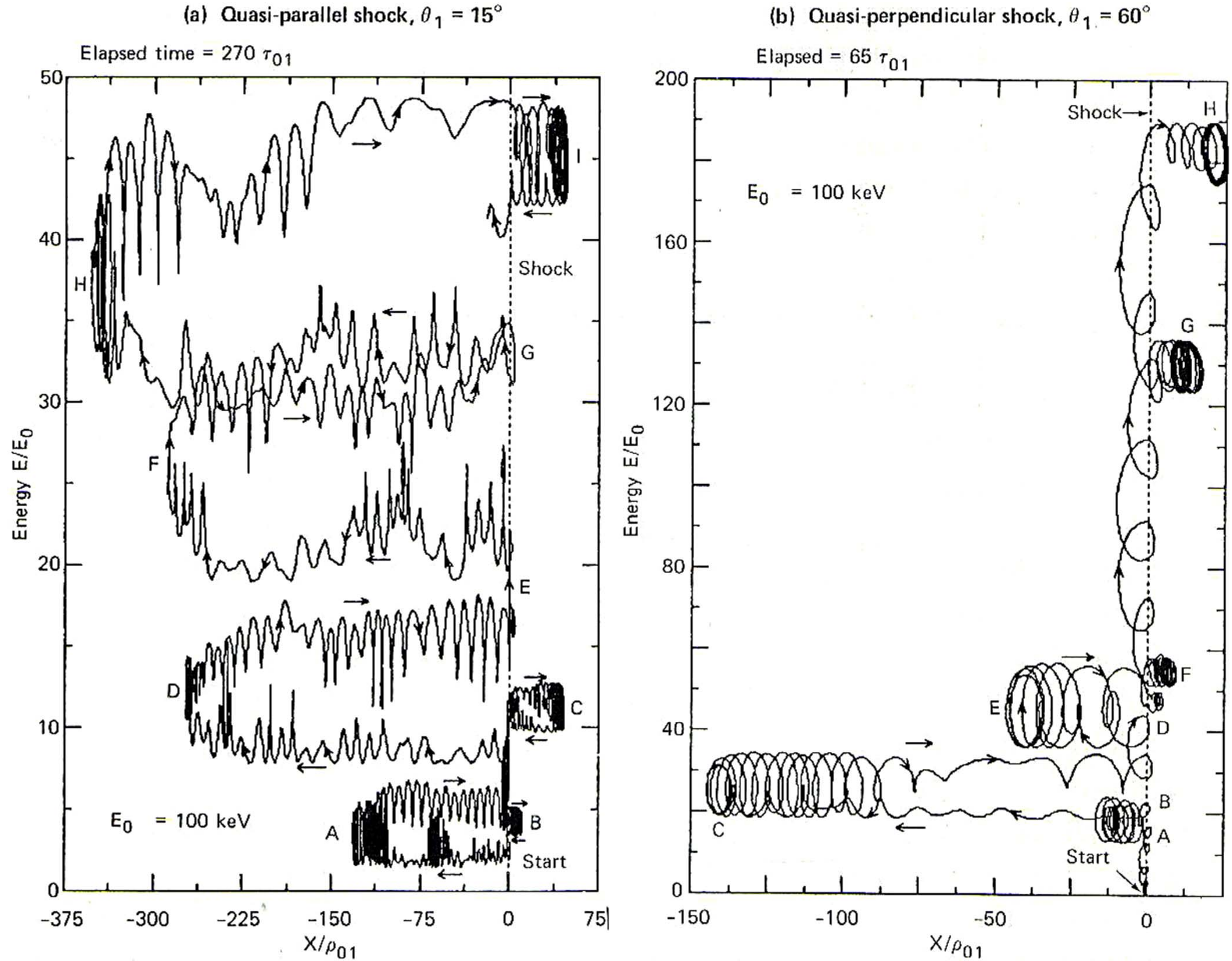


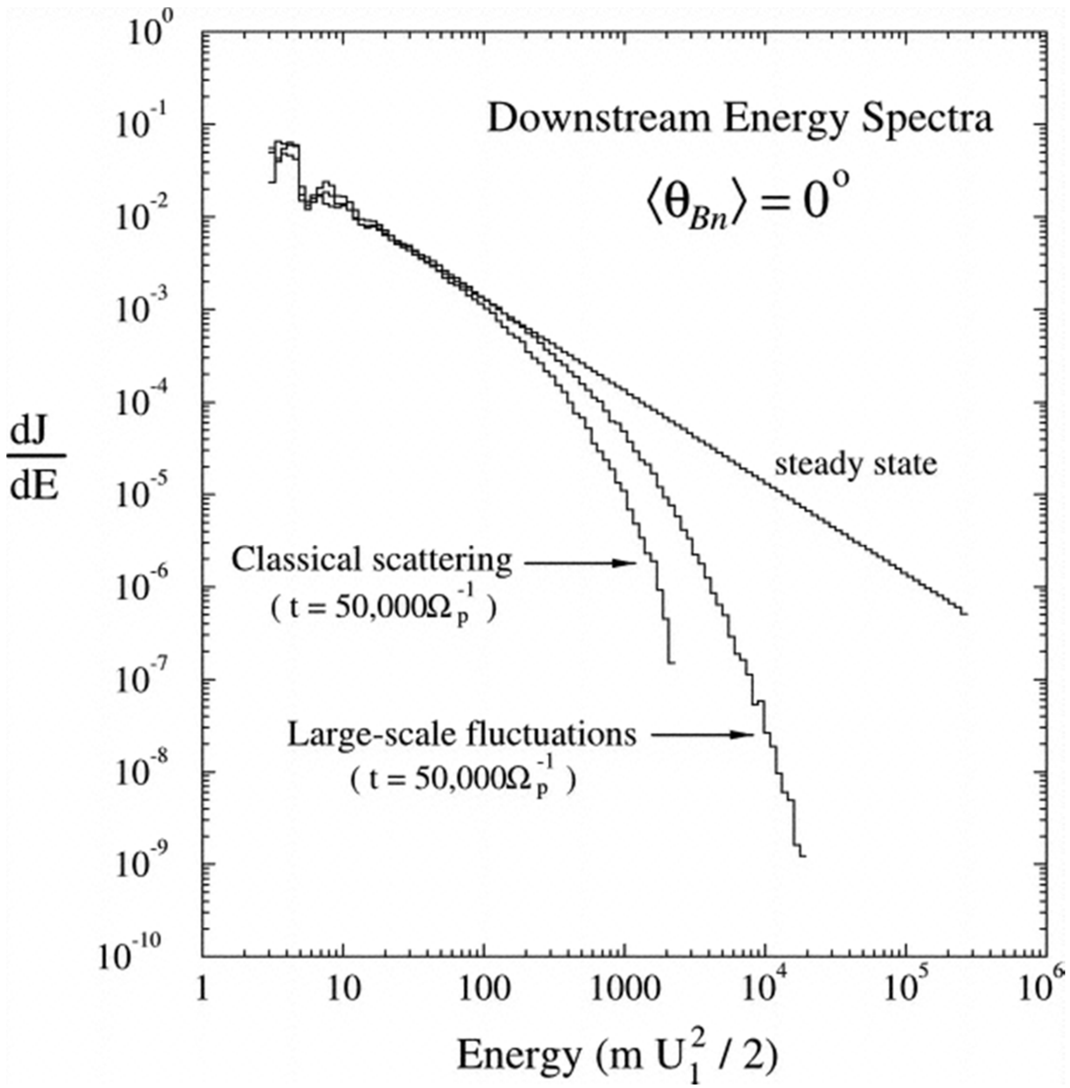
Test particle simulations of shock acceleration injecting protons into a pre-existing shock at different shock normal angles. One notes that the flattest spectrum is obtained for small θ_{Bn} in the quasi-parallel shock, but the dependence is weak. The difference is only in the flux with the quasi-parallel 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



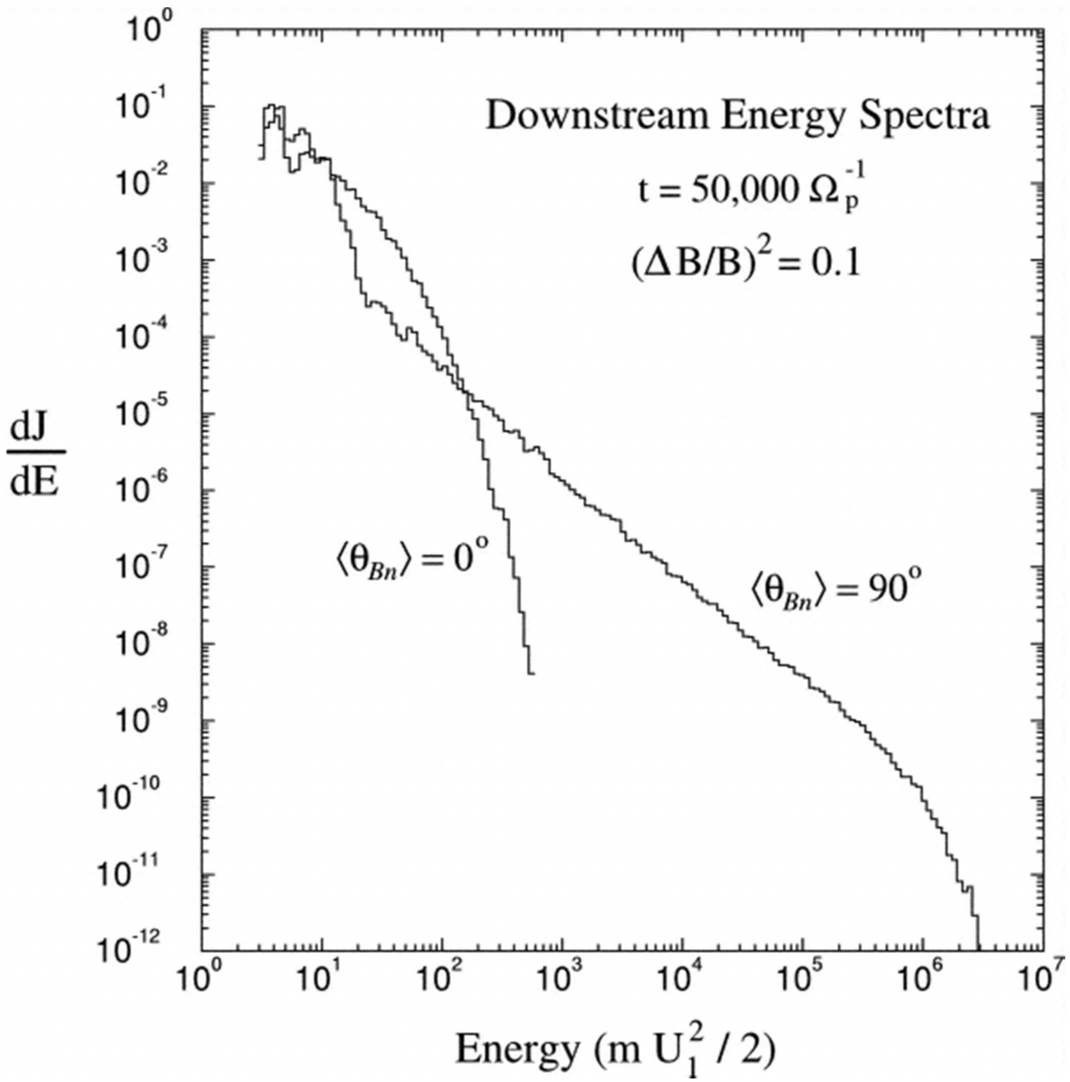
Slower Acceleration **More Rapid Acceleration**

Decker (1988)



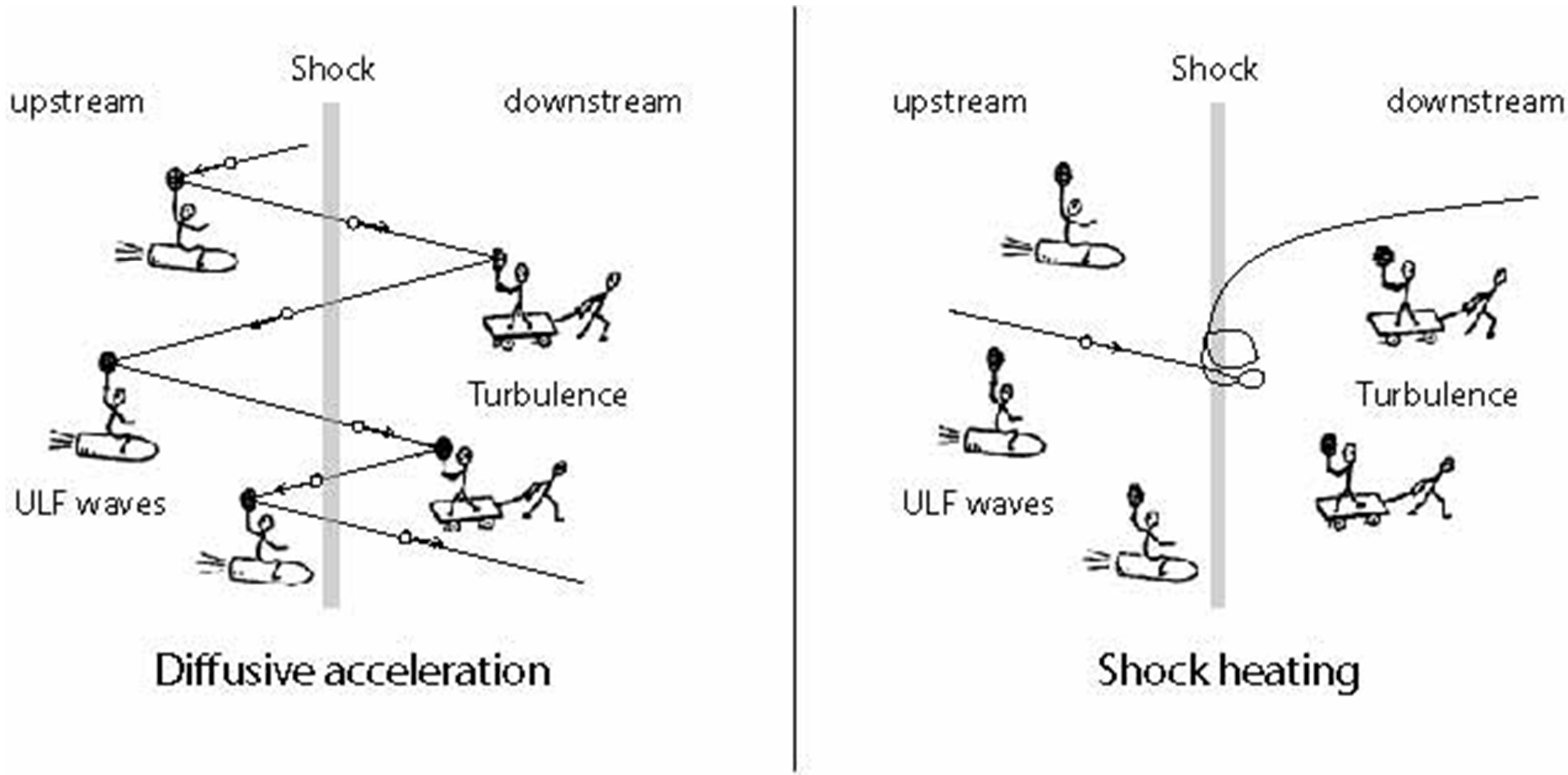
The large-scale fluctuations lead to a higher acceleration rate at a parallel shock compared to the case of simple first-order Fermi acceleration (the classical scattering case). This is due to the fact that, at times, the local magnetic field is more oblique to the shock normal. Thus, even for a parallel shock (on average), acceleration can occur locally at the shock because of drift acceleration.

http://iopscience.iop.org/article/10.1086/429265/meta



For the weak turbulence case, the acceleration rate at a parallel shock is very small because the particle mean free paths are very large. However, the perpendicular shock readily accelerates particles to very high energies because these particles are capable of diffusing normal to the mean magnetic field direction by following meandering magnetic field lines.

http://iopscience.iop.org/article/10.1086/429265/meta



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

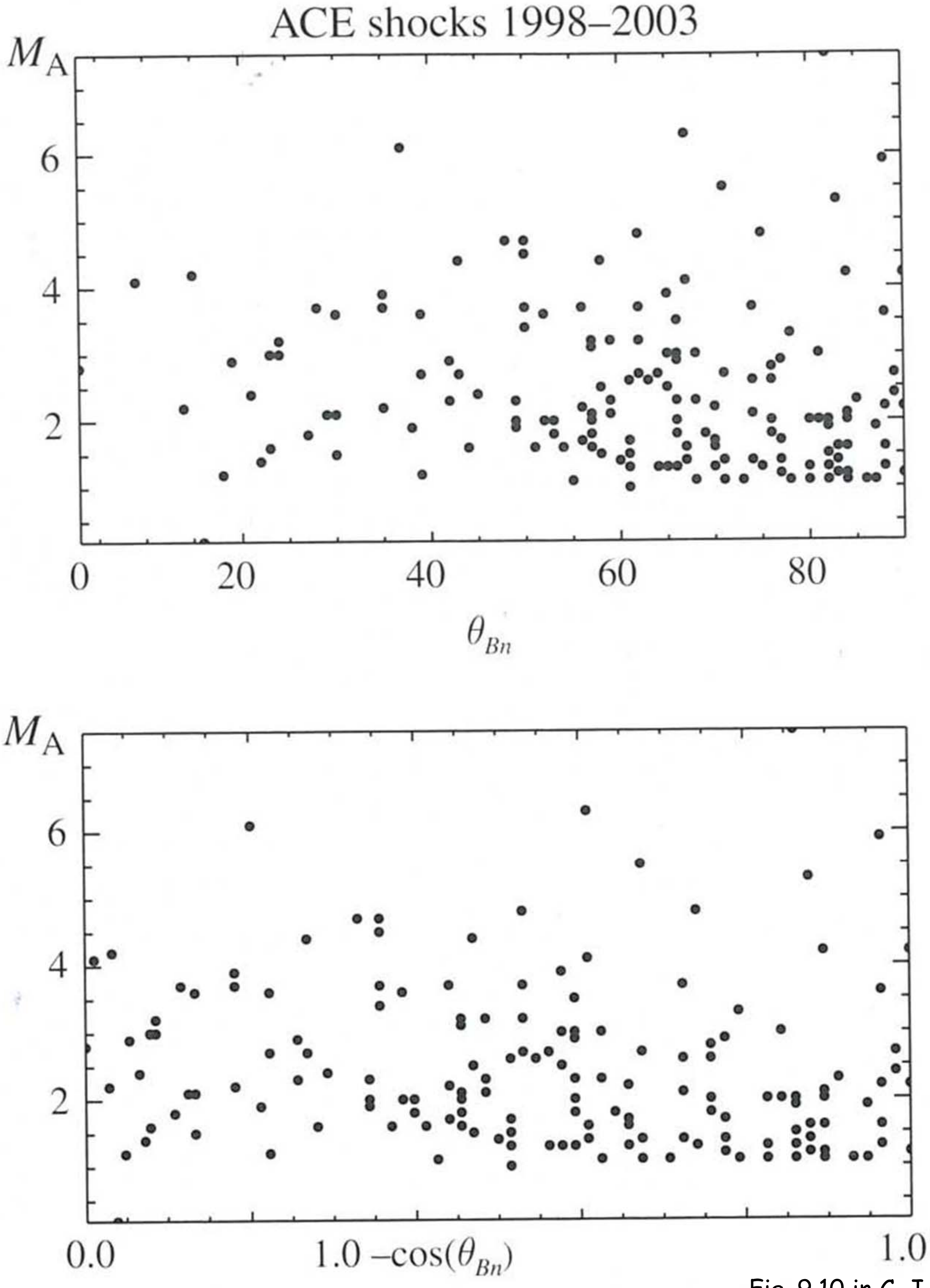
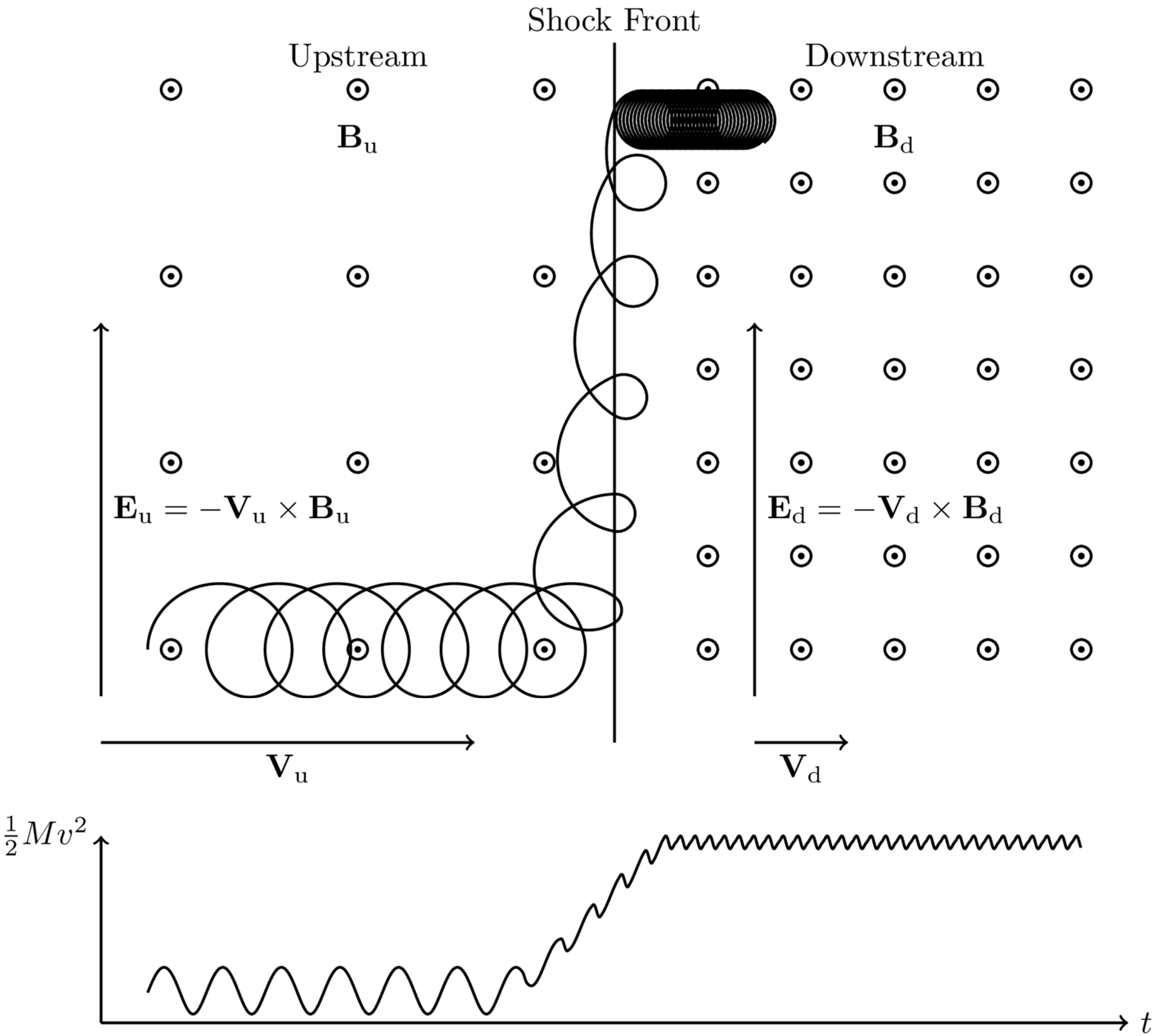
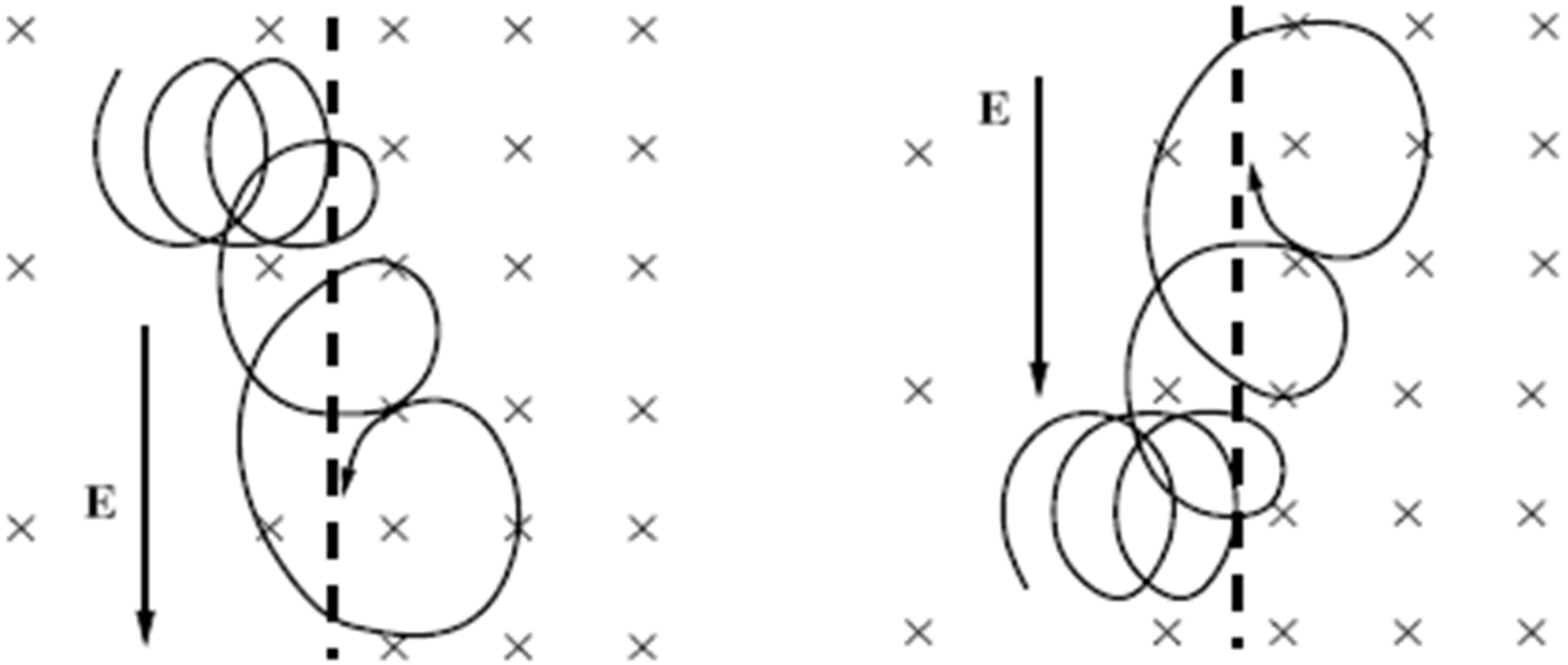


Fig. 9.10 in C. J. Schrijver and G. L. Siscoe (2010)

Shock Drift Acceleration



http://sprg.ssl.berkeley.edu/~pulupa/illustrations/shockdrift/shockdrift.png

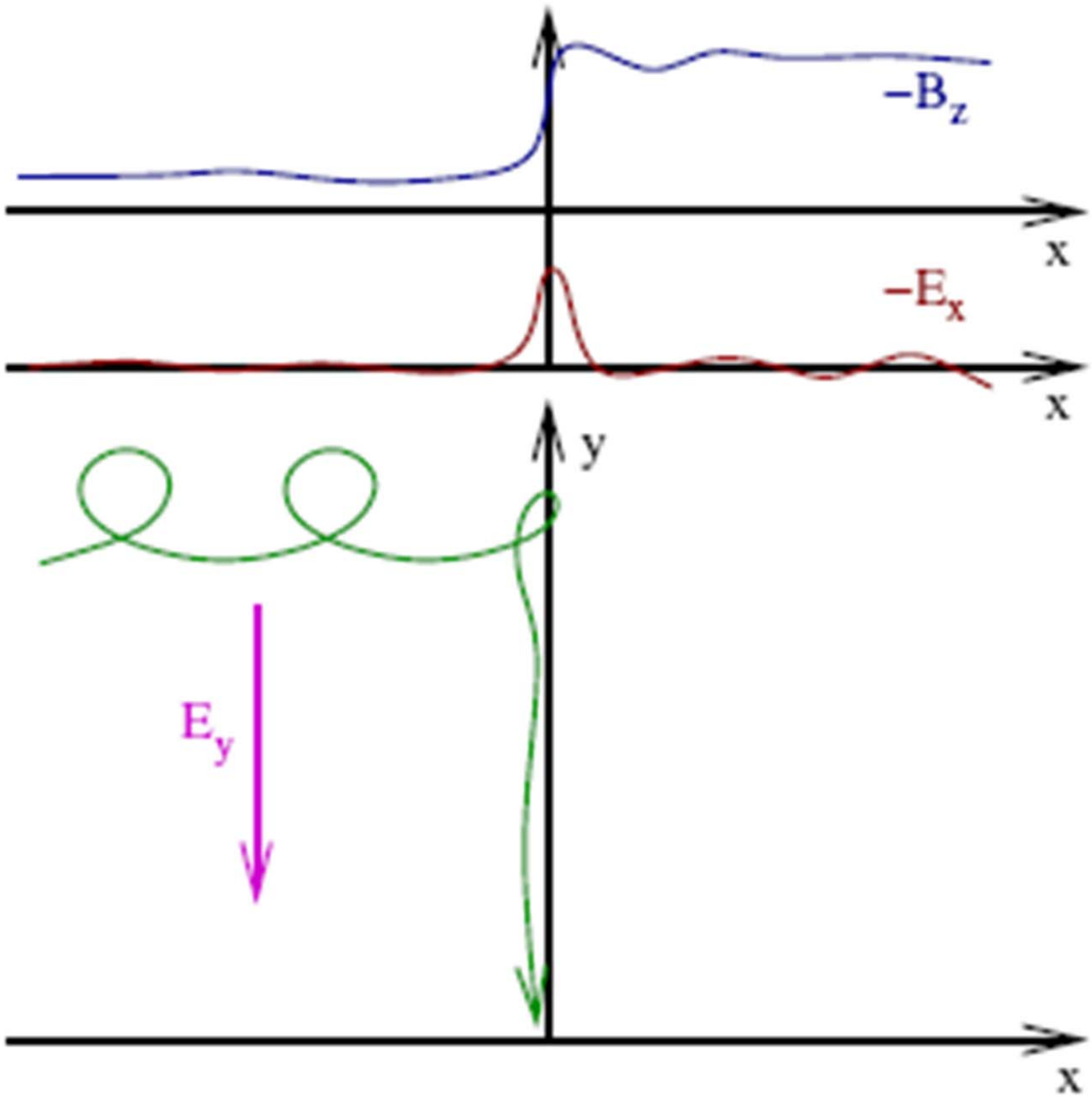


ions drift parallel to the E-field
electrons drift anti-parallel to the E-field
→ both ions and electrons are accelerated

Operates in oblique shocks as well.

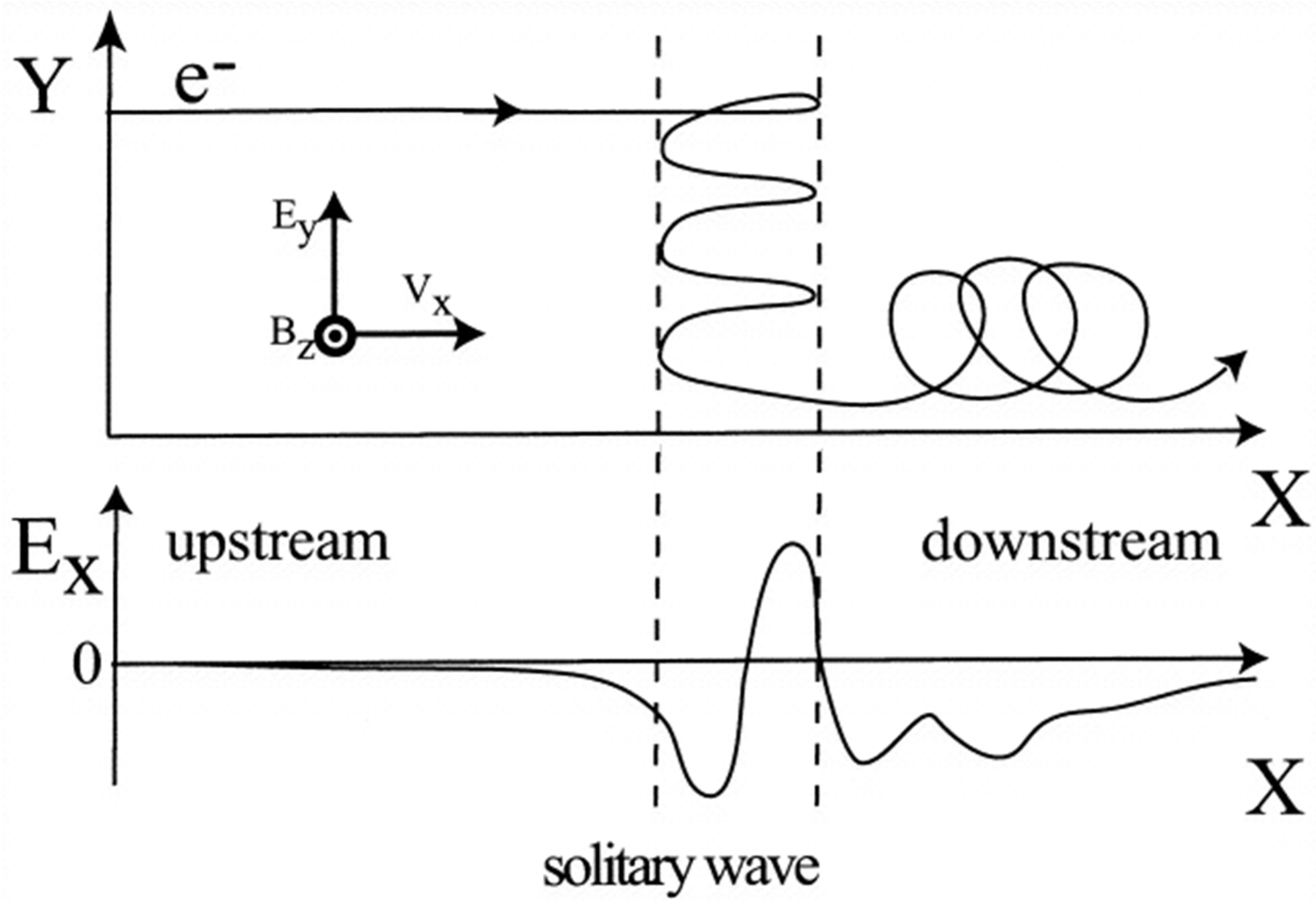
Vainio (2009)

Shock Surfing Acceleration



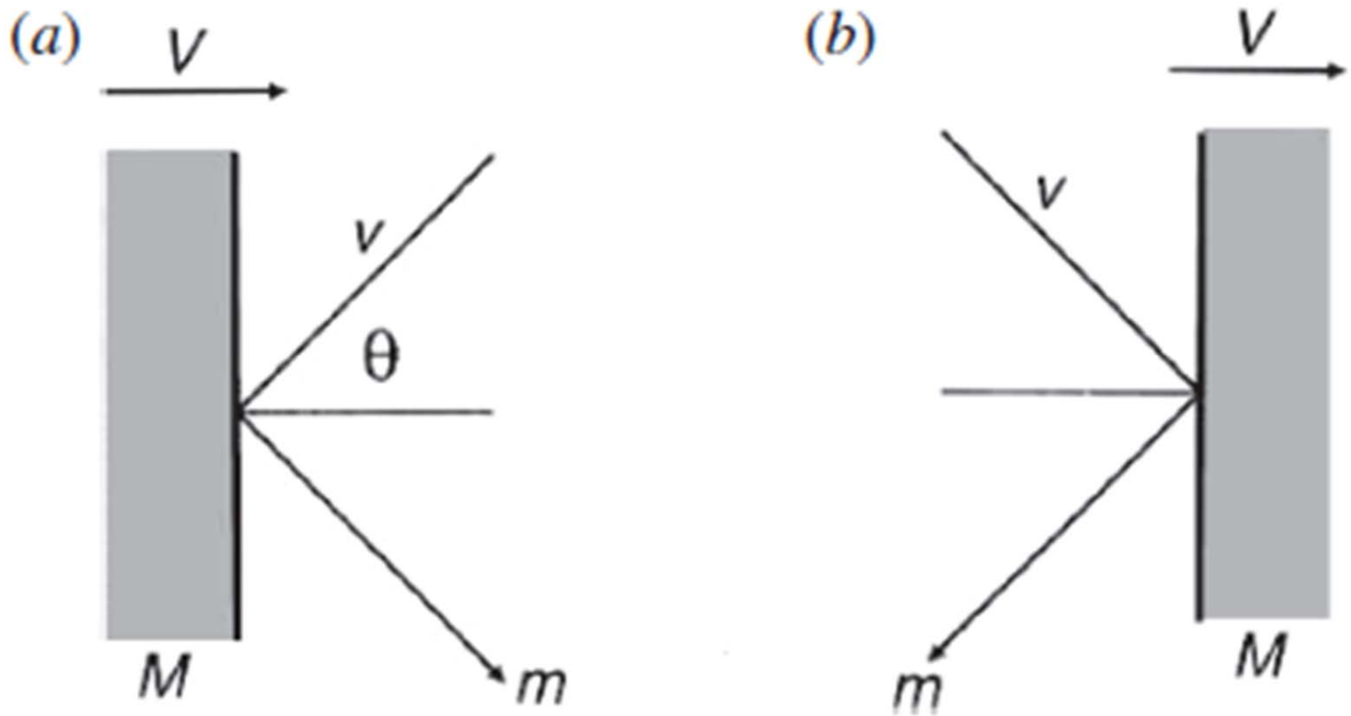
Surfing requires an almost exactly perpendicular shock.

Vainio (2009)



http://iopscience.iop.org/article/10.1086/340454/fulltext/55422.fg6.html

Second-order Fermi acceleration



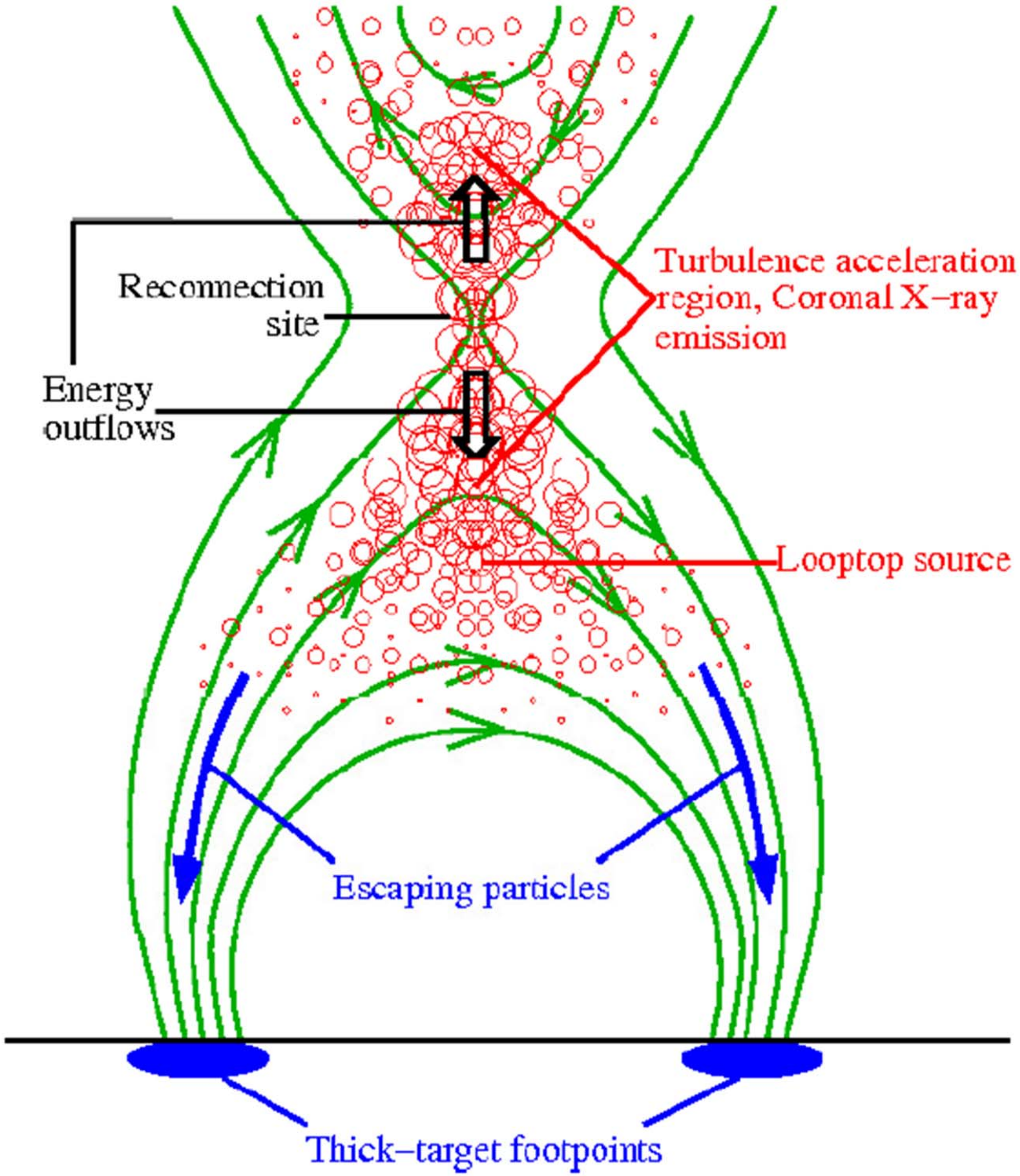
Energy is (a) gained during a head-on collision and (b) lost during a trailing collision.

Cosmic rays bouncing between moving ISM clouds. Gain energy with head-on collision. Lose energy with overtaking collision.

This second-order process was not fast enough to overcome ionization losses for heavy elements in ISM.

https://www.cfa.harvard.edu/~namurphy/Lectures/Ay253_08_ParticleAccel.pdf

stochastic acceleration



Petrosian (2012)

Plasma in the 400 km/s solar wind takes 4.3 days to travel 1 AU.

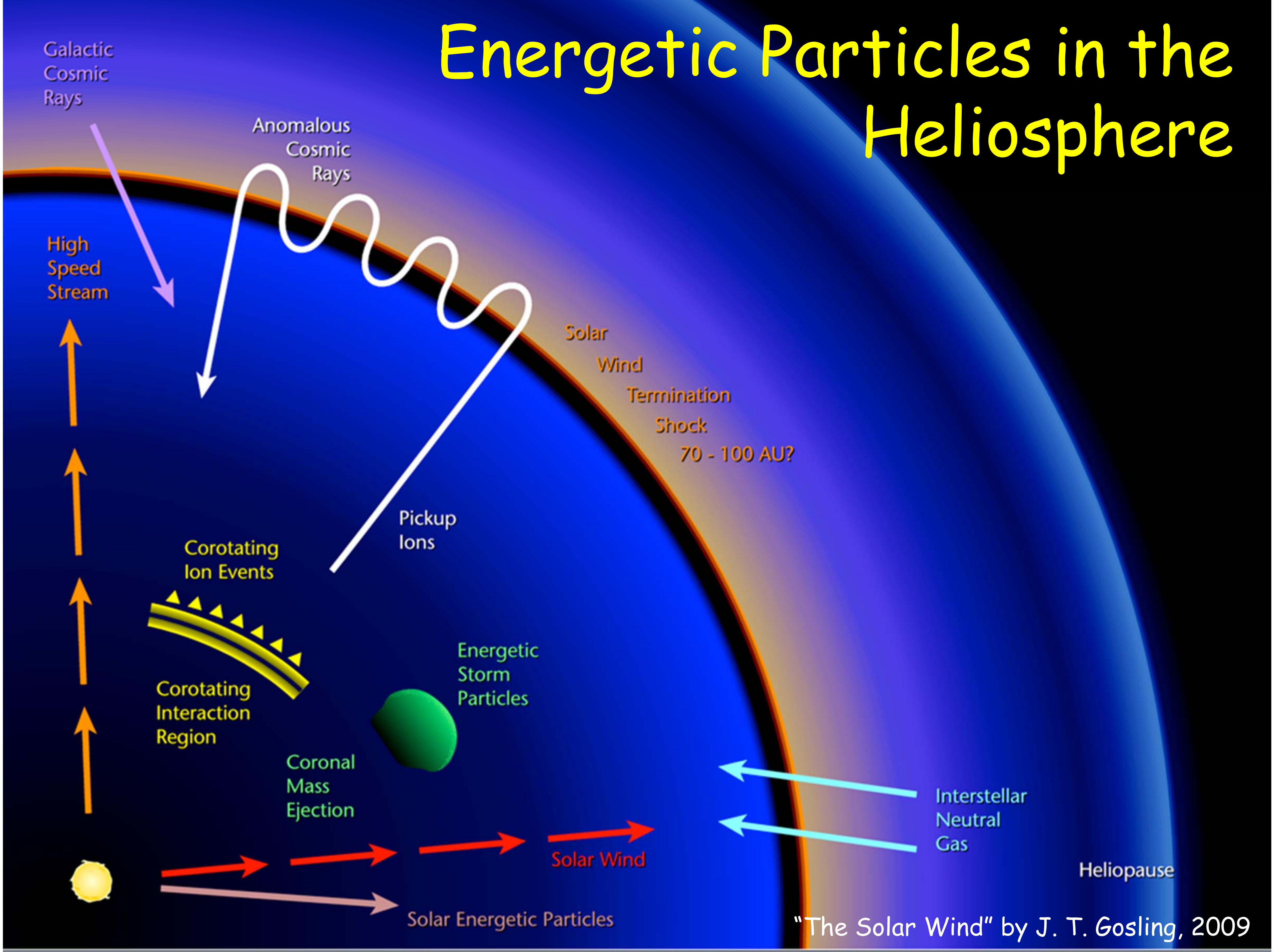
A shock wave with an average speed of 1700 km/s takes 1 day.

A 10 MeV proton or a 5 keV electron takes an hour.

A photon of light takes 8.3 min.

Thus, it is not surprising that particles accelerated by a shock wave near the Sun arrive near Earth long before the arrival of the shock itself.

Energetic Particles in the Heliosphere



"The Solar Wind" by J. T. Gosling, 2009

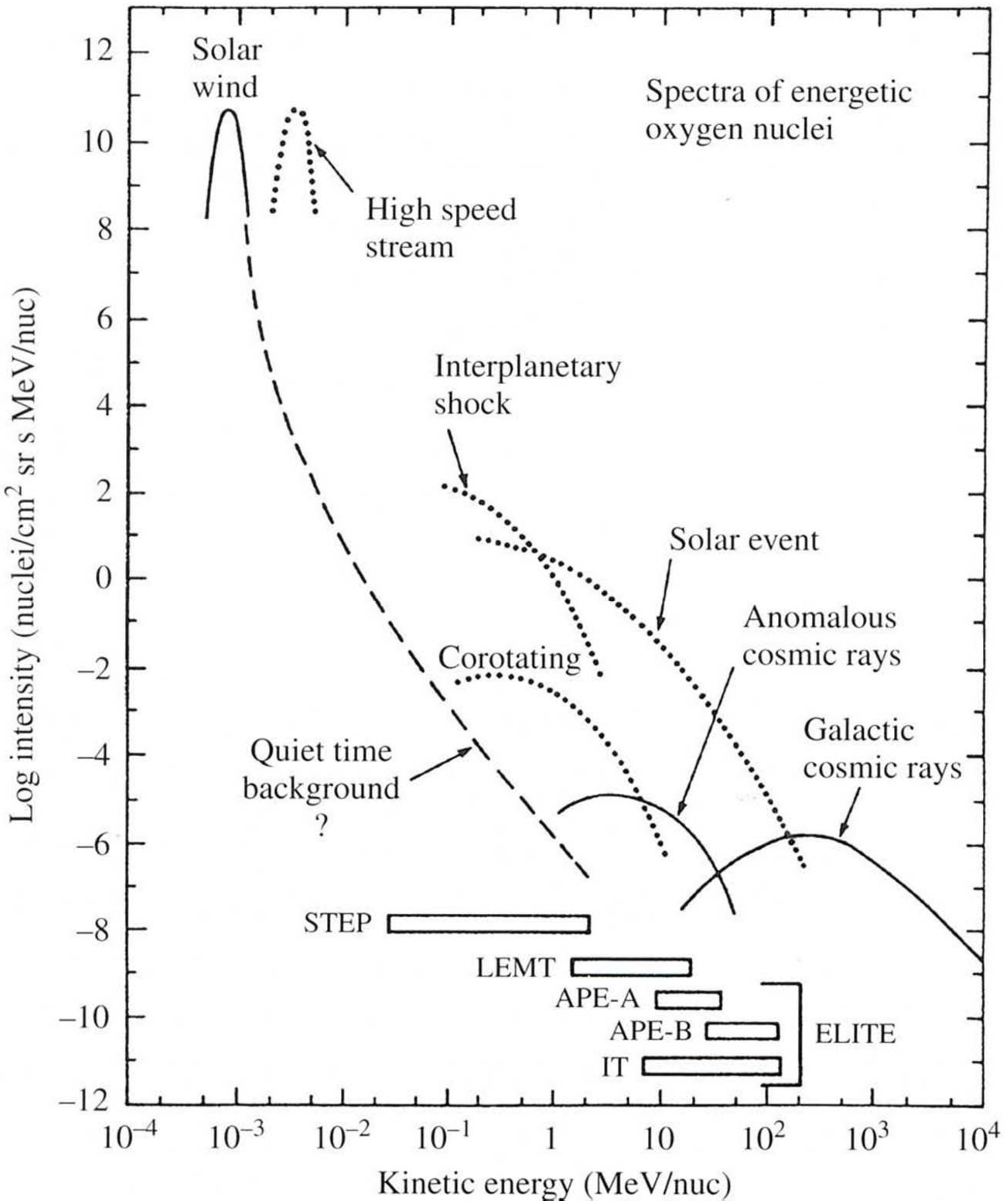
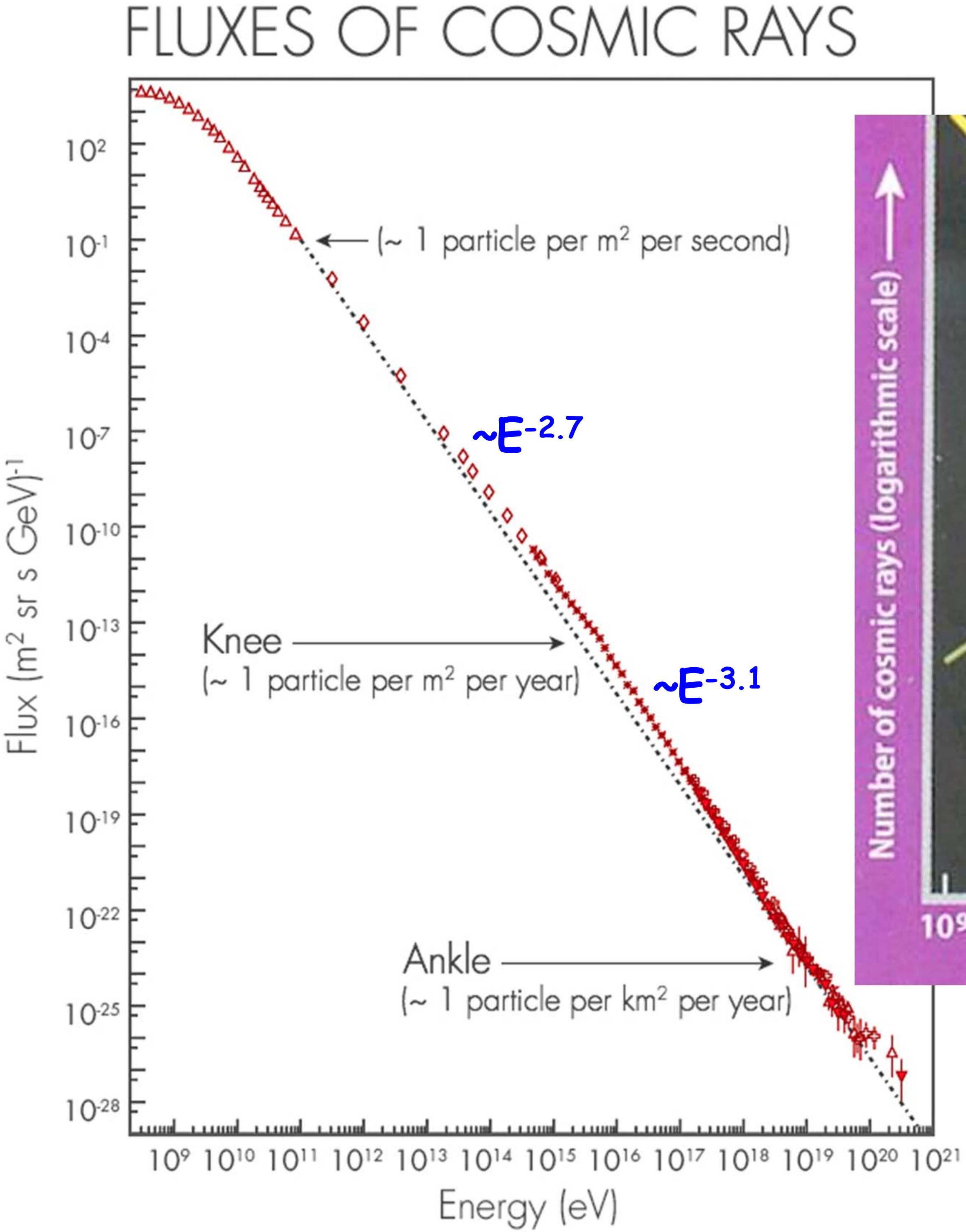
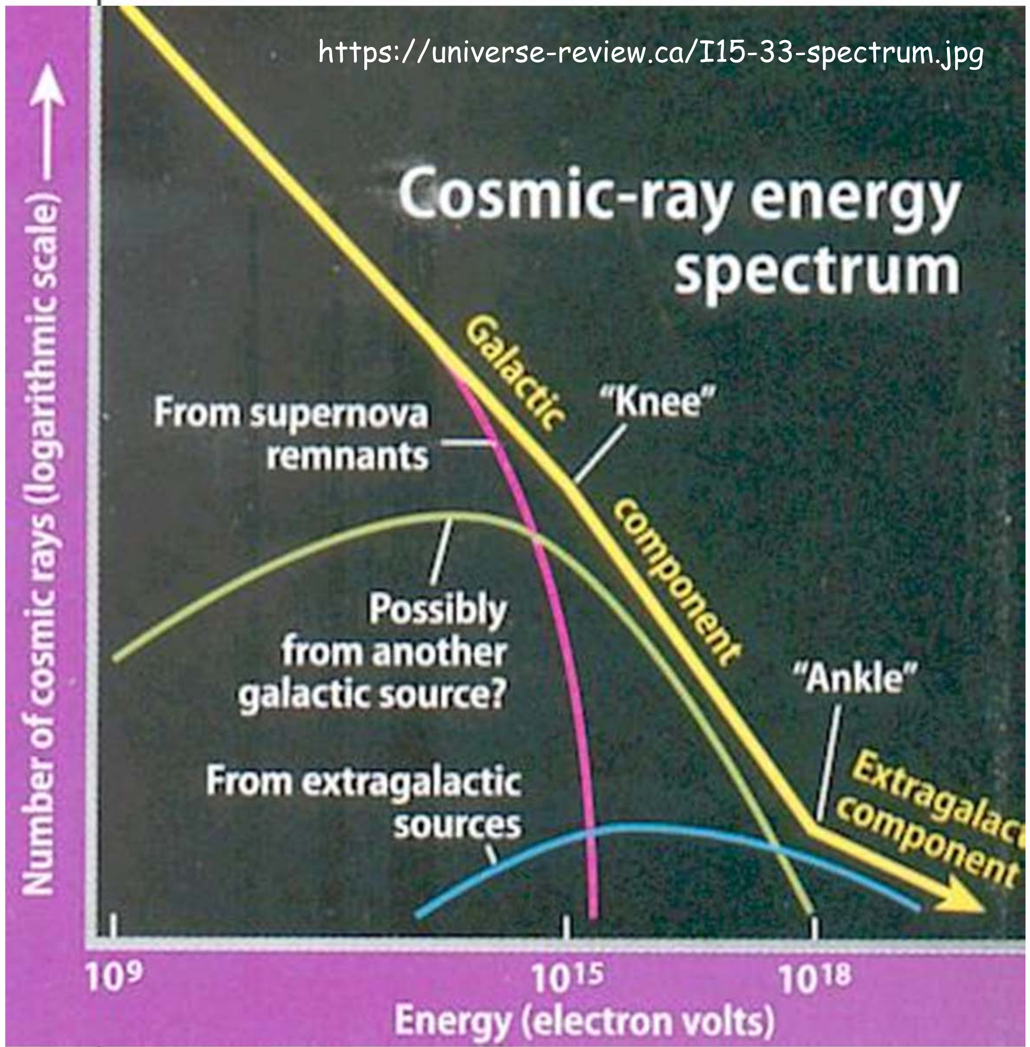
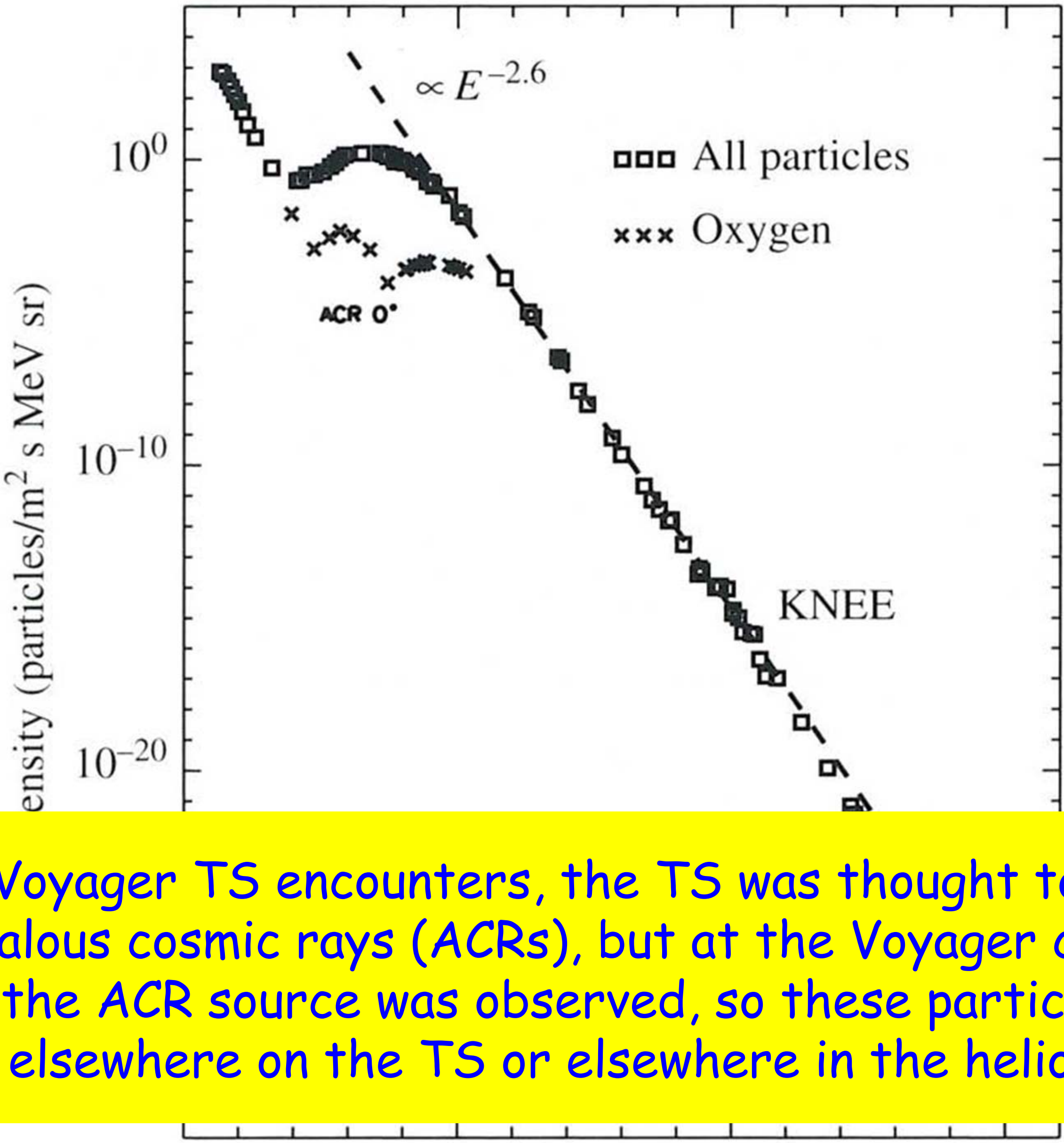


Fig. 9.1 in C. J. Schrijver and G. L. Siscoe (2010)





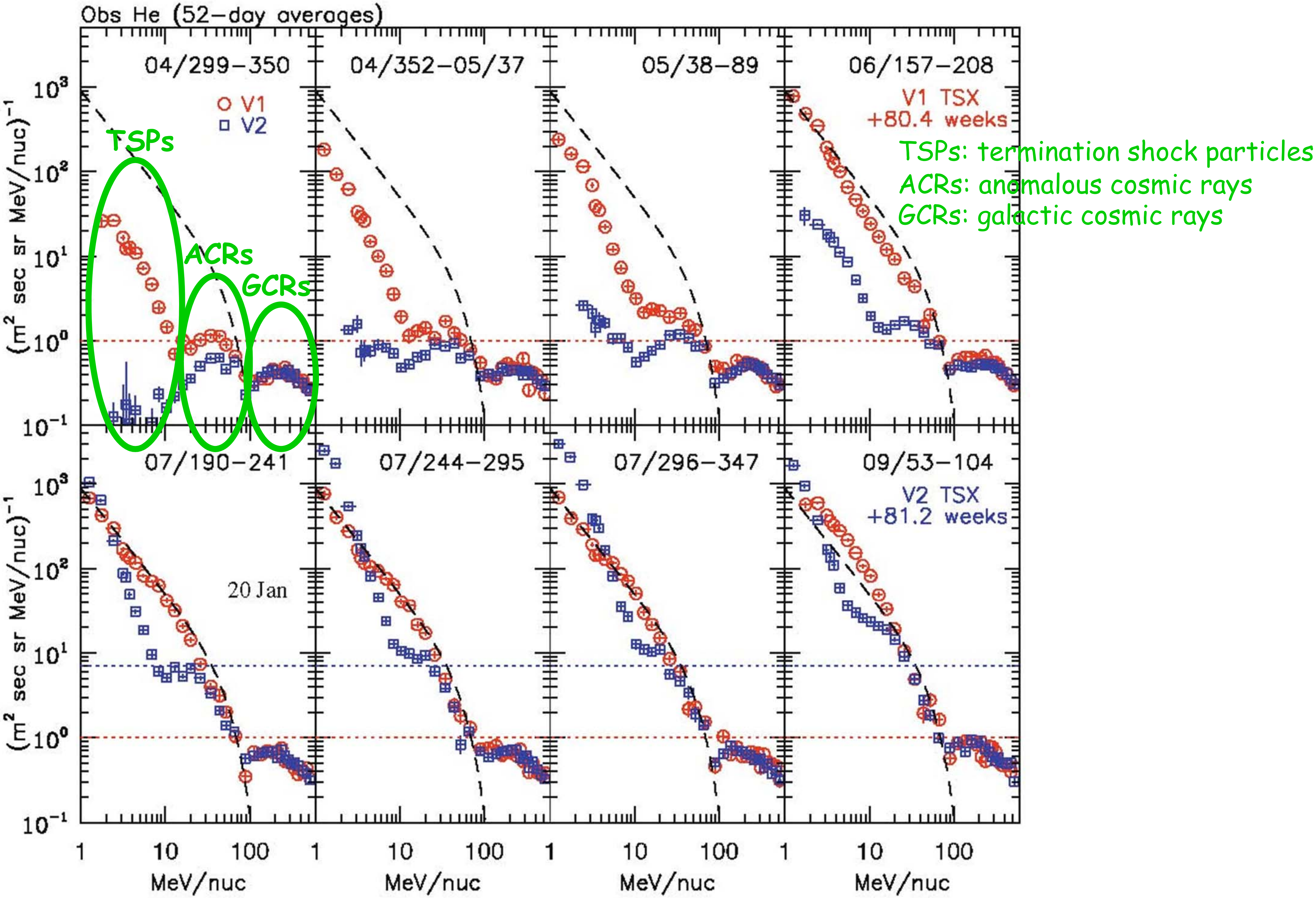
https://www.quantamagazine.org/wp-content/uploads/2015/05/SwordyCosmicRaySpectrum_v1.jpg



Before the Voyager TS encounters, the TS was thought to be the source of the anomalous cosmic rays (ACRs), but at the Voyager crossing no evidence of the ACR source was observed, so these particles must be accelerated elsewhere on the TS or elsewhere in the heliosphere.

ACRs increase in intensity with radial distance from the Sun, indicating that this component probably originates in the interaction of the solar wind with the interstellar medium.

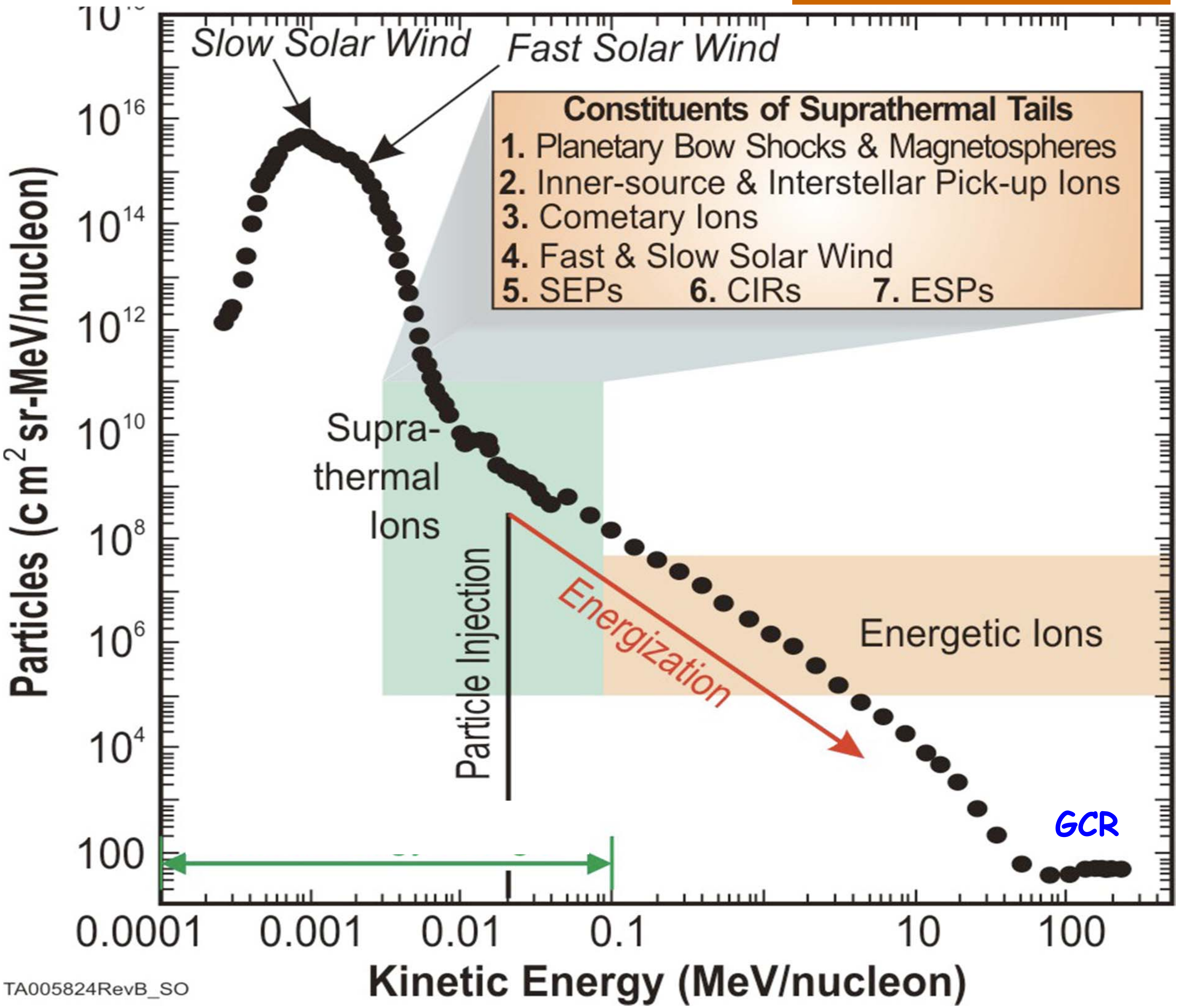
Fig. 9.2 in C. J. Schrijver and G. L. Siscoe (2010)



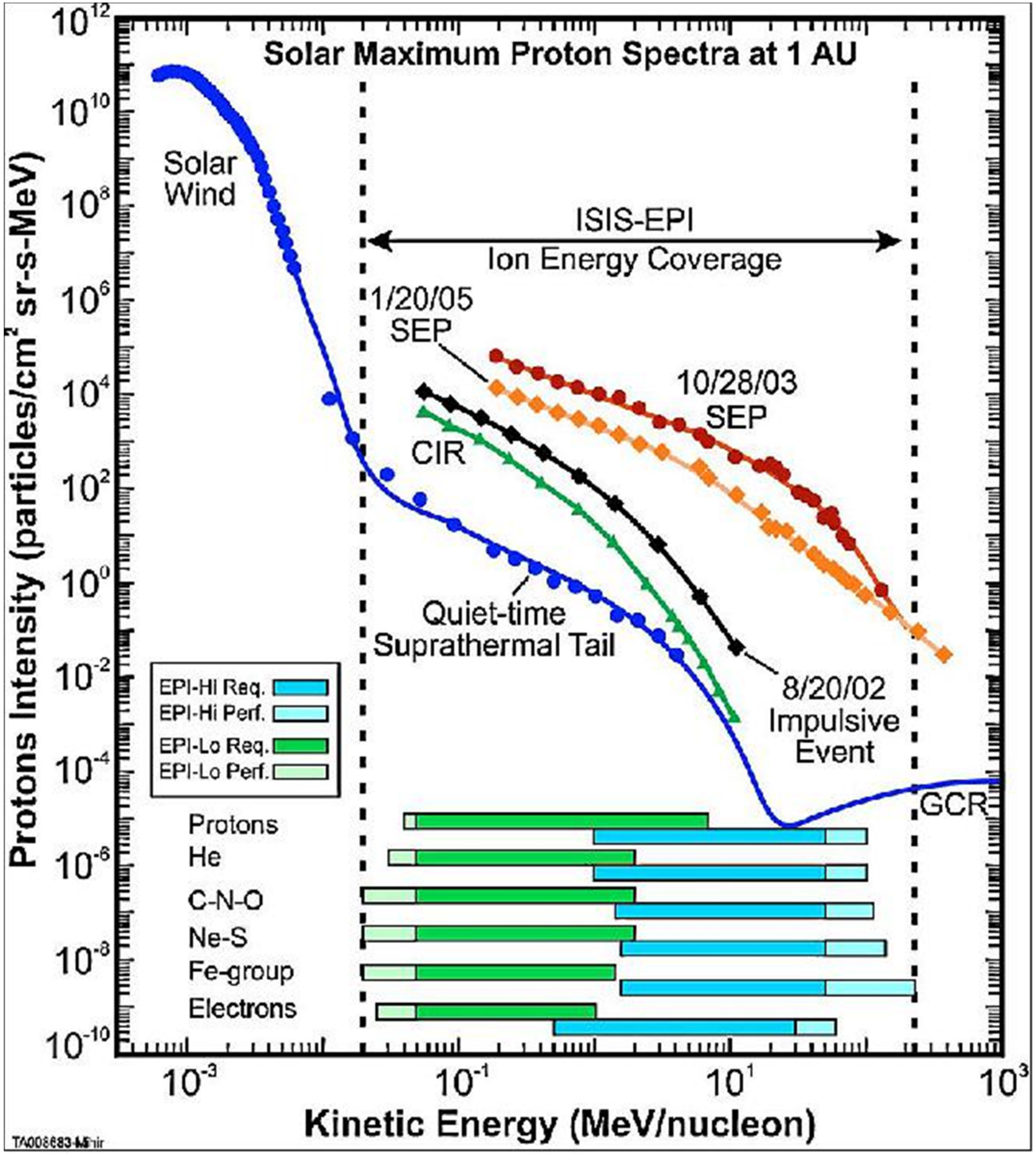
The lowest energy TSP fluxes increase across the TS, but the ACR particle intensities do not change. The ACR fluxes have continued to increase with distance, and the power spectra have continued to unroll towards a power law. At the highest energies the ACRs are not modulated.

Fig. 13.7 in M. P. Miralles and J. Sánchez Almeida (2011)

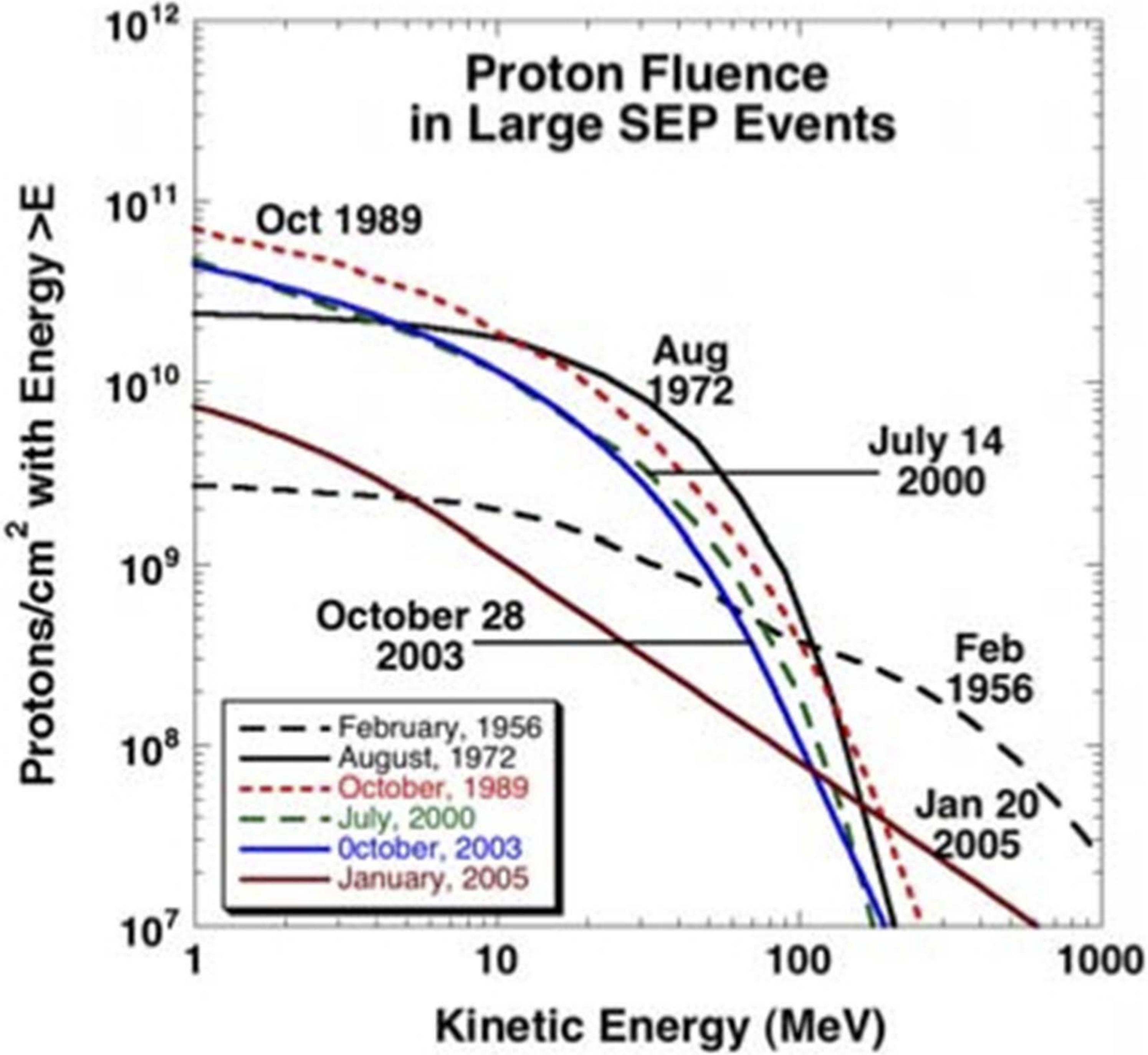
(Mewaldt et al., 2001)



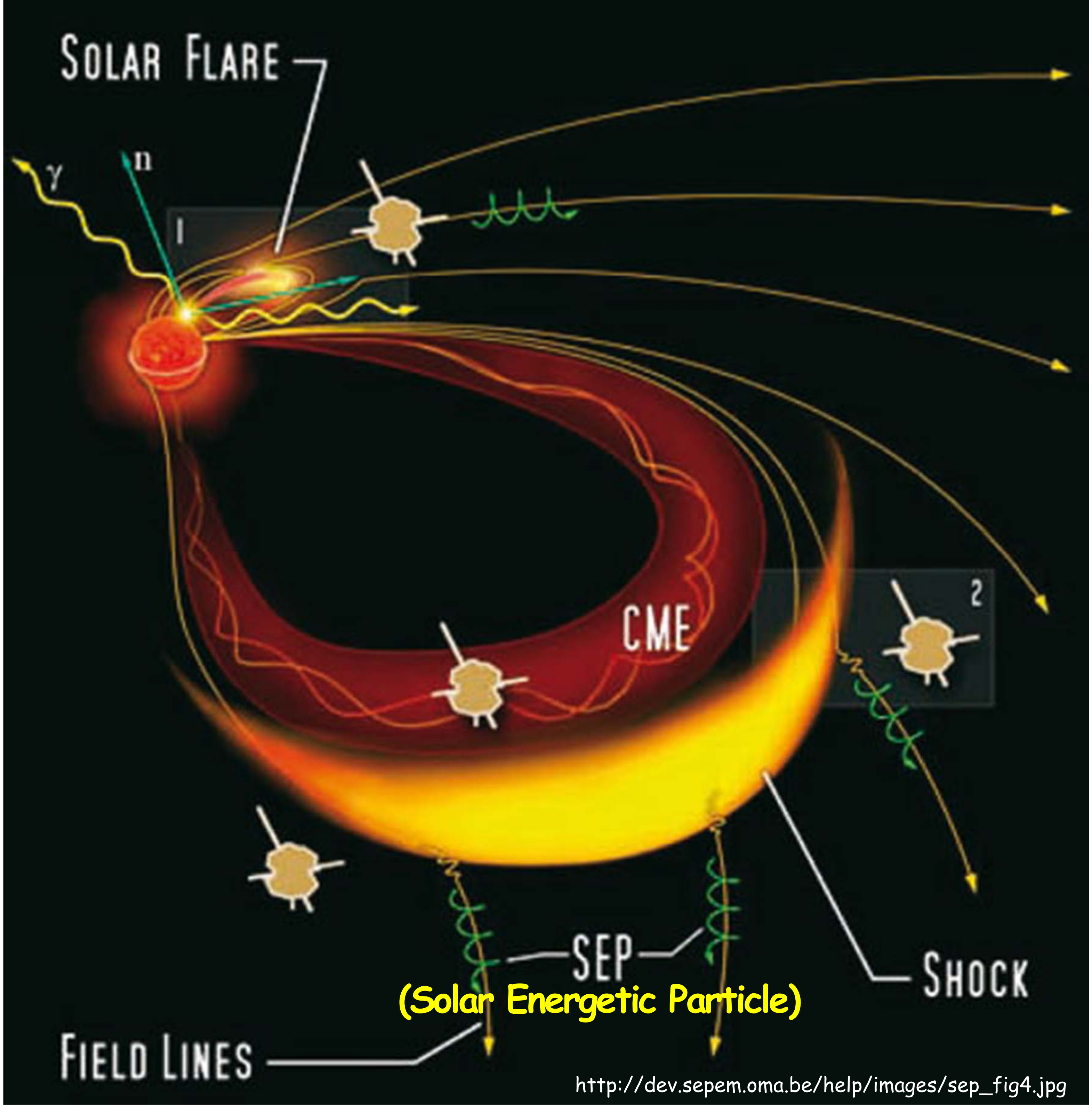
Gang Li in 2014 iSWWS



https://directory.eoportal.org/web/eoportal/satellite-missions/s/spp#vOpZN12f8Herb



http://www.sciencedirect.com/science/article/pii/S0094576514003798



SOLAR FLARE
γ
n
1
2
CME
SEP
(Solar Energetic Particle)
SHOCK
FIELD LINES
http://dev.sepem.oma.be/help/images/sep_fig4.jpg

Twin-CME

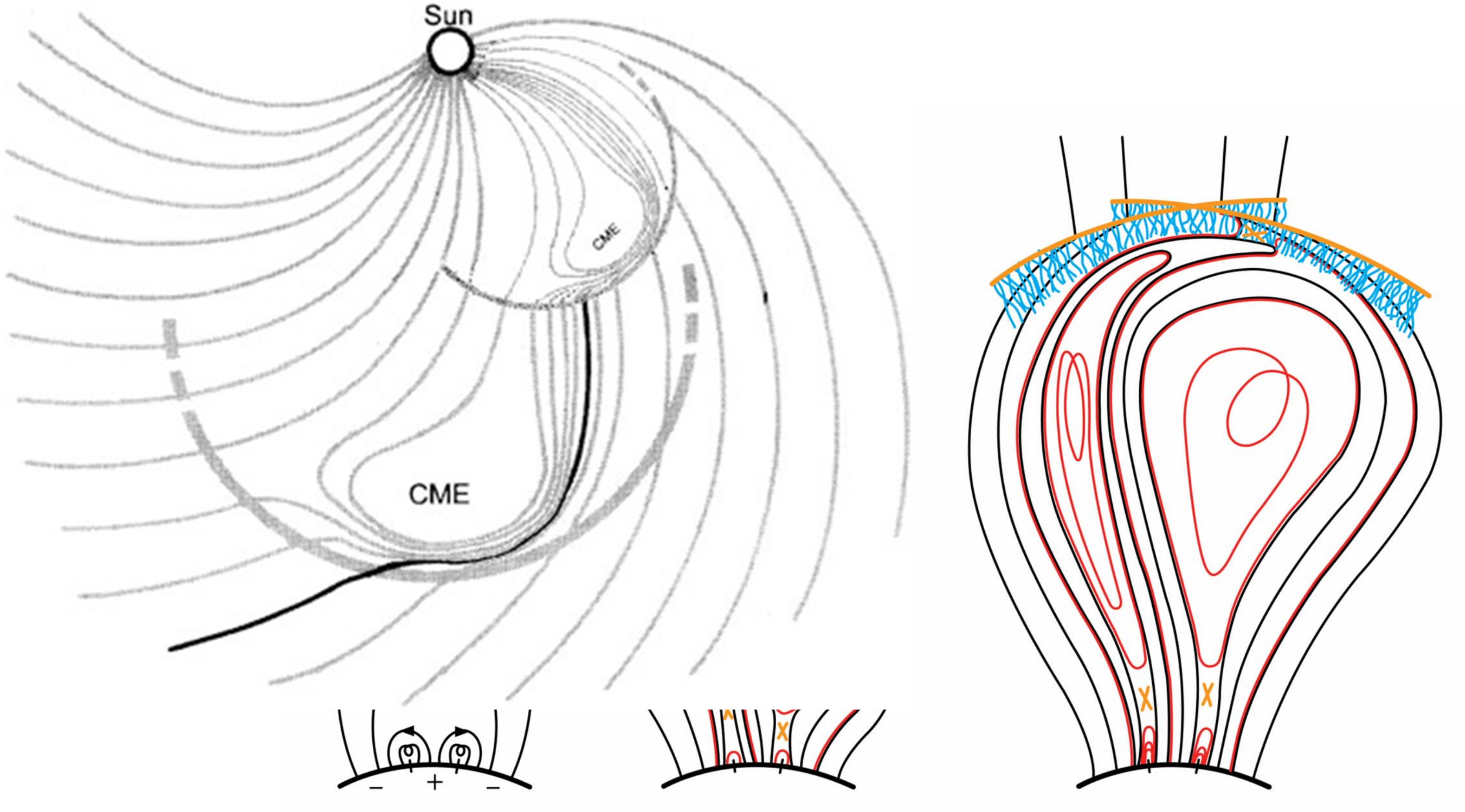


Fig. 3.12 in Donald V. Reames (2017)

Gang Li in 2014 iSWWS