Particle acceleration at ultrarelativistic shocks in gammay-ray burst outflows

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Particle acceleration at ultrarelativistic shocks hinges on the ability of particles to cross the shock front repeatedly. Standard treatments assume this is made possible by diffusion in angle brought about by magnetic turbulence in both the upstream and downstream regions [1]. However, it is well-known that ultrarelativistic shocks are generically perpendicular [2], which has led to the assertion that acceleration will be ineffective, unless the turbulence in the downstream medium is strong enough to demagnetize the particles there [2,3,4].

Here, we use an eigenfunction expansion method, complemented by Monte-Carlo simulations, to show that ultrarelativistic shocks are indeed effective particle accelerators even when they fail to produce large amplitude turbulence in the downstream plasma, contradicting the widely held belief. In the ultrarelativistic limit, we find a stationary power-law particle spectrum of index $s = 4.17$ for these shocks, close to that predicted for a strictly parallel shock [5]. We then apply the same technique to the blast wave of a gamma-ray burst that is driven by a magnetic piston. In this case, we show that the resulting spectrum hardens towards higher energy, with a break point whose energy depends on the extent to which an MHD shock detaches itself from the piston and propagates ahead of it into the ambient medium.

References

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