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Solar Energetic Particles: Wave Generation and Particle Acceleration at Shocks

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Ion and electron acceleration at shock waves accounts for many if not most of the energetic particle enhancements observed throughout the heliosphere. In most cases the association between the energetic particles and shocks is clear. In other cases, including the so-called anomalous cosmic rays and the high-energy solar energetic particles observed following the onset of well-connected solar flare events, the association has been less clear and more controversial. The theory of shock acceleration is first reviewed including the shock drift mechanism, the theory of diffusive shock acceleration (DSA), and some of the complications that occur when applying simple versions of these processes to observed shocks and particle enhancements. A critical feature of DSA is that the upstream accelerating protons excite hydromagnetic waves, which dramatically decrease the timescale for acceleration. The waves are transmitted at the shock to enhance the downstream wave intensity, they affect particle injection out of the solar wind at the shock, and they can grow to sufficient amplitudes upstream that nonlinear processes become important. Several examples of wave and energetic particle enhancements will be shown.